POST-CONSUMER RECYCLED ALUMINIUM FOR AEROSOL VALVES

by

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Dedication

To my husband, Klaus Gausmann, whose memory continues to inspire every step I take.

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I want to express my deepest gratitude to my academic supervisor, Dr. sc. Hrvoje Volarevic, whose invaluable guidance, constructive feedback, and unwavering support have been the cornerstone of this doctoral research. His expertise and encouragement have not only shaped the quality and direction of this work but also my academic journey.

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On a personal note, I am grateful to my parents for their unwavering love, patience, and faith in my abilities.

Finally—and most importantly—I dedicate this work to the memory of my late husband, Klaus Gausmann. His specific ways of support and motivation were my greatest inspiration. His memory has been a source of strength throughout this endeavour, and this dissertation is dedicated to him.

ABSTRACT

POST-CONSUMER RECYCLED ALUMINIUM FOR AEROSOL VALVES

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2026

Dissertation Chair: <Chair’s Name>

Co-Chair: <If applicable. Co-Chair’s Name>

This study examines the environmental and economic feasibility of using 100% post-consumer recycled (PCR) aluminium in aerosol valve mounting cups. While aluminium is theoretically infinitely recyclable, challenges arise in meeting the strict alloy and surface-quality requirements for these niche applications. (Stacey 2015).

The research compares two low-carbon strategies: sourcing primary aluminium from energy-efficient producers and increasing the use of PCR aluminium. Findings show that, despite its environmental appeal, PCR aluminium faces significant constraints, including limited availability of alloy-compatible scrap and inconsistent aesthetic properties.(European Aluminium, 2025c)

Drawing on industry reports and literature, the study highlights that current recycling systems are insufficient to deliver the required purity and volume. Although the use of PCR aluminium could reduce carbon emissions, practical limitations hinder its broad adoption in specialised packaging components. Further research and industry collaboration are needed to close the gap between sustainability goals and technical feasibility in these markets. (Reinhardt, 2023)

This dissertation investigates the environmental benefits of using 100% post-consumer recycled (PCR) aluminium in the production of aerosol valve mounting. Using a causal-explanatory research design, the study examines the impact of increasing PCR content on the carbon footprint of aluminium packaging components and assesses the technical feasibility of replacing traditional alloys (e.g., 5754) with more widely available PCR-compatible alternatives, such as aluminium grade 3104. (Aditya Birla Novelis, 2022)

Using a deductive, empirical approach, the study tests the hypothesis that both first-class primary aluminium (sourced from low-carbon smelters) and 100% PCR aluminium can significantly reduce greenhouse gas emissions. Primary and secondary data are collected from aluminium producers, packaging suppliers, and industry publications. (Karbach-Parr, 2019)

Initial findings confirm that while PCR aluminium lowers CO_2 emissions (0.5–0.6 t CO_2/t Al vs. ~10 t for primary), alloy purity and scrap availability remain significant constraints. The research proposes 3104 as a viable alternative to enable broader adoption of PCR aluminium and establishes a benchmark for sustainable innovation in niche aluminium packaging segments.

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LIST OF ABBREVIATIONS

CO2	Carbon Dioxide
EN-AW	European Norm Standards (EN) – Aluminium Wrought Alloy (AW)
GHG	Greenhouse Gas
IAI	International Aluminium Institute
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
PCR	Post-Consumer Rezyklat
PIR	Post-Industrial Rezyklat
Ra	Roughness Average
RM	Tensile Strength
RP	Yield Strength
RZ	Mean Roughness Depth

CHAPTER I:

INTRODUCTION

1.1. Introduction

The 21st century is increasingly characterised by the growing importance of sustainability, reflecting a global shift towards responsible production, resource efficiency, and environmental stewardship. Protecting the climate by mitigating global warming is a crucial topic today. There are ongoing discussions about carbon emissions and their potential impact on the Earth's environment. This study focuses on the environmental aspects of sustainability in aluminium production. The research aims to quantify and analyse CO_2 emission differentials between primary and post-consumer recycled aluminium using a life-cycle assessment (LCA) approach applied to aerosol valves and associated packaging components.

Throughout Earth’s history, a correlation has existed between global temperatures and greenhouse gas concentrations. Approximately 4.5 billion years ago, during the early history of the planet, Earth’s atmosphere was primarily composed of carbon dioxide, accounting for about 80% of its total gases. The Earth was covered in molten lava at its earliest stage of formation. It was uninhabitable. The origin of CO2 was mainly volcanic.(Varenholt and Lüning, 2020)**.**

Over the following 3.5 billion years, atmospheric CO2 content decreased rapidly. CO2 was fixed in limestones, hydrocarbons, and plants and dissolved in ocean water. The first signs of life emerged approximately 1 billion years ago, marked by the appearance of single-celled organisms, which were followed by the development of an oxygenated atmosphere. 550 million years ago, the Earth's atmosphere had a CO2 concentration of 0.7%, equivalent to 7,000 ppm (parts per million). Approximately 400-500 million years ago, CO2 levels ranged from 5,000 to 2,000 parts per million (ppm).

Dinosaurs started roaming the Earth approximately 100 million years ago. In the late Devonian period, CO2 concentration decreased again. During the Carboniferous and Permian periods, CO2 concentrations were similar to those of today, approximately 400 ppm. During the Triassic, Jurassic, and Cretaceous periods, the CO2 content increased to values of 1000-2000 ppm. The CO2 peak of this Mesozoic phase was in the Jurassic. In the subsequent Cretaceous and Tertiary periods, the CO2 concentration steadily decreased. About 1 million years ago, the CO2 content dropped to 300 ppm. Approximately 10 million years ago, the era of mammals and the direct ancestors of humans began. Only 100,000 years ago, homo sapiens truly evolved.

Throughout Earth's history, human communities have had a negligible impact on CO2 emissions. Humans have accounted for only a small percentage, with no significant relative effect on the global emission rate. Historically, there were only small communities; humans and their domesticated animals worked. This rapidly changed in the 20th century with the introduction of machinery for industrial and agricultural production and the development of the transportation system.

From around 100 million years ago until the end of the last ice age, approximately 10,000 years ago, scientific evidence indicates that atmospheric CO_2 levels fluctuated naturally and repeatedly, ranging from 200 ppm during cold, glacial periods to 350 ppm during warm, interglacial periods. (United States Department of Energy, 1985).

At the end of the last great glaciation, as the Earth gradually warmed approximately 18,000 years ago, atmospheric CO2 levels began to rise. It reached typical interglacial levels of 265-280 ppm approximately 11,000 years ago. This range was not exceeded until the start of anthropogenic emissions. Analysis of an Antarctic ice core has shown that CO2 levels during the Medieval Warm Period were approximately 10 ppm higher than during the following Little Ice Age.

Starting with industrialisation at the beginning of the 19th century, CO2 concentrations rose above interglacial levels. It began with a relatively slight increase in the 1800s, then accelerated, reaching its current level around 1970. The additional CO2 concentration in the atmosphere primarily results from the use of fossil fuels, as well as from cement production and changes in land use. Approximately half of these anthropogenic CO2 emissions are absorbed by the oceans and stored by plants, while the other half accumulates in the atmosphere.

The current CO2 concentration in the atmosphere is 414 ppm (0.0414 %, as of 2020). The atmospheric concentration increases by approximately two ppm per year. The last time CO2 levels were as high as today's was in the Pliocene, approximately 3 million years ago.

Regular temperature and CO2 measurements were not done before 1980. Since the Industrial Revolution, carbon dioxide emissions have continued to increase; CO2 concentration has risen from 330 to 420 ppm; and global temperatures have increased by 0.8 °C. Global warming describes the long-term rise in Earth's average temperature, recorded since the pre-industrial era. It is largely attributed to human-induced factors such as fossil fuel combustion, industrial processes, and deforestation, which collectively increase the concentration of greenhouse gases in the atmosphere. Carbon dioxide emissions are a primary driver of global warming. On the one hand, there are CO2 sources that add CO2 to the system; on the other hand, there are CO2 reducers that remove it. Zero emissions are therefore not necessary to reduce the CO2 concentration in the system (Lindsay and Dahlmann, 2024).

Substantial carbon stocks are held within the oceans, terrestrial biomass, and the atmosphere, forming a dynamic system in which carbon is continually cycled and exchanged.(Kerr, 2017) Around 120 billion tons of carbon are exchanged between land and the atmosphere every year, mainly through photosynthesis by plants. The oceans and atmosphere exchange an additional 80 billion tons of carbon annually via gas processes at the sea surface. Human activities, including the use of fossil fuels and cement manufacturing, are responsible for releasing an additional 10.4 billion tons of carbon into the atmosphere annually, thereby intensifying the greenhouse effect and exacerbating global warming. Although the anthropogenic contribution accounts for only a small part of the annual carbon cycle, it disrupts a long-established balance. The stability of atmospheric CO_2 concentrations over the 10,000 years preceding industrialisation implies that fluxes between CO_2 sources and sinks remained in dynamic equilibrium. Currently, this balance has been disrupted, resulting in increased atmospheric CO2 levels.

The greenhouse effect was first described by Joseph Fourier in 1824 and further detailed by Svante Arrhenius in 1896. Short-wave radiation from the sun can pass through the Earth's atmosphere largely unhindered. On Earth's surface, energy is converted to heat and radiated as long-wave infrared radiation, which is prevented from escaping into space by greenhouse gases. Greenhouse gases absorb the heat and release it in all directions, including towards the Earth's surface, ultimately leading to the warming greenhouse effect. The most important greenhouse gases are water vapor (H2O), carbon dioxide (CO2), ozone (O3), nitrous oxide (N2O) and methane (CH4). (Allwood, 2016) Natural greenhouse gases play a vital role in maintaining Earth's temperature balance; without them, heat would escape unimpeded into space, lowering global temperatures by about 33 °C and leaving the planet frozen and inhospitable.

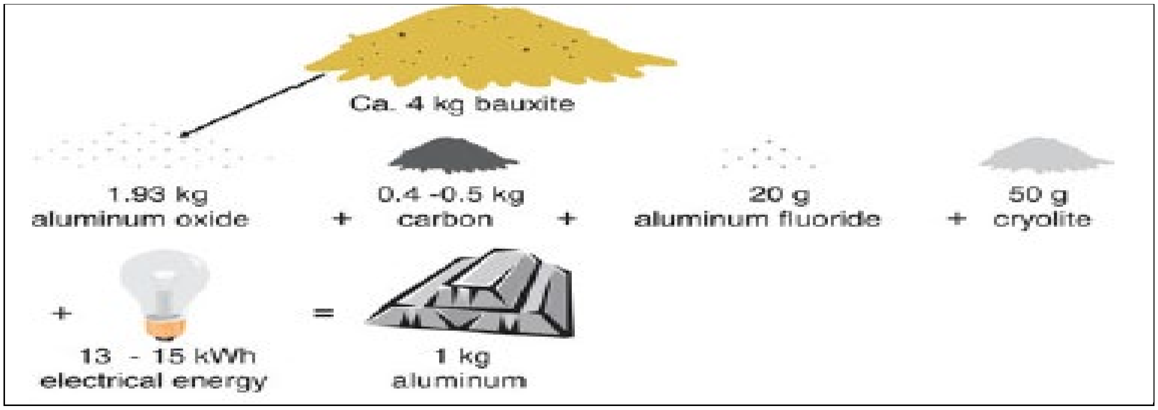
The public climate debate is not usually about whether CO2 warms the Earth's temperature, but rather how much it warms. It is, therefore, primarily a quantitative question. Unfortunately, it is difficult to determine the exact warming effect through experiments or theoretical calculations. There is only a consensus on one aspect. If carbon dioxide were the only influencing factor, without additional feedback processes, a doubling of its atmospheric concentration would raise the Earth's average temperature by about 1 °C. This is not a significant factor in the overall warming effect of CO2, as additional factors may either increase or decrease it.

The effect of CO_2 on global temperature is logarithmic in nature; consequently, a doubling of atmospheric CO_2 concentration is necessary to generate the same increment of warming as the previous increase. The usual CO2 content of the atmosphere for the current interglacial period is just under 300 ppm. Therefore, doubling would be achieved at just under 600 ppm.

1.2. Aluminium Mining and Processing

Producing aluminium requires substantial energy, resulting in high CO_2 emissions. The process begins with bauxite mining, as this ore—found in the topsoil of tropical and subtropical zones—serves as the primary source of aluminium. Bauxite is mined and subsequently processed into alumina (aluminium oxide) through the Bayer process, which chemically extracts aluminium from the ore. The amount of raw materials needed to produce 1 kilogram of aluminium is.

Figure 1: The Aluminium Smelting Process

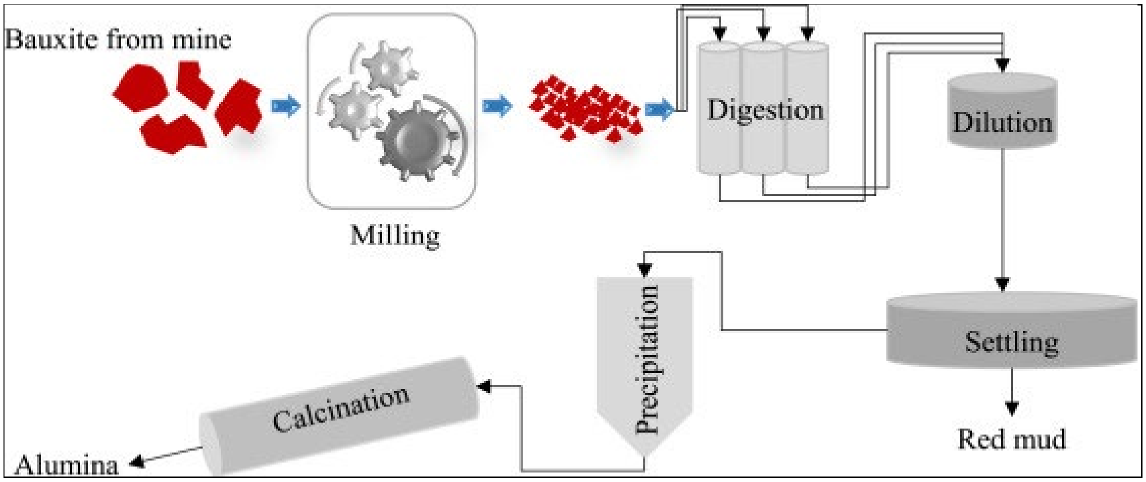


Source: *(Kvande and Drabløs, 2014)*

The Bayer process, introduced by Carl Josef Bayer in 1888, refines bauxite into alumina (Al_2O_3), the intermediate compound used in aluminium production. Producing one ton of alumina typically requires 1.9 to 3.6 tons of bauxite. The refining process includes digestion, clarification, precipitation, and calcination. (Hind, Bhargava and Grocott, 1998)

The resulting alumina serves as the feedstock for the Hall-Héroult process, in which it is dissolved in molten cryolite at about 950 °C. Through electrolytic reduction, using carbon anodes, aluminium metal is separated and collected as a molten layer at the bottom of the cell. The metal is then transferred to holding furnaces and cast into ingots for subsequent fabrication. The Hall-Héroult process, while essential for producing primary aluminium, is characterised by substantial electricity consumption and the release of process-related CO_2 emissions, making it the dominant contributor to the industry's overall carbon footprint. (Hind et al. 1998).

Figure 2. Alumina Production

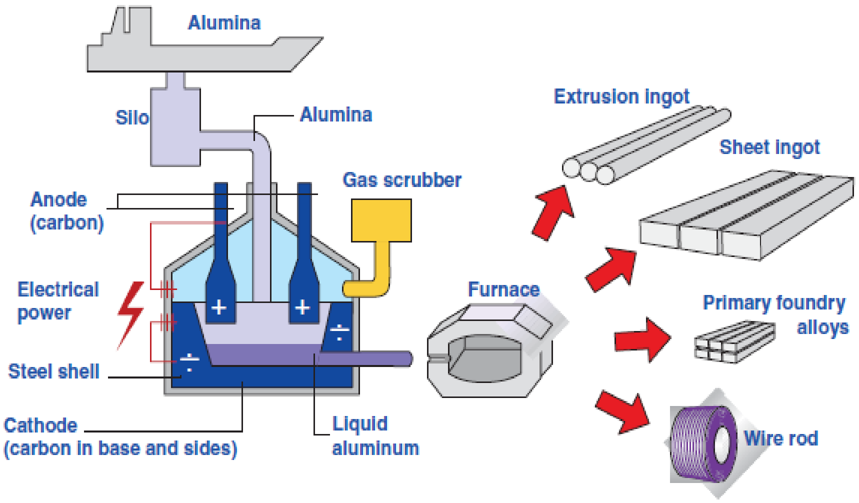


Source: *(Fundamentals of Aluminium Metallurgy 2011)*

Electric power accounts for roughly 20–40% of the total cost of primary aluminium production. In the United States, around 5% of national energy output is devoted to aluminium manufacturing each year. (Kerr, 2017)

Primary aluminium production involves the electrolytic reduction of alumina, predominantly through the Hall–Héroult process. Secondary aluminium production encompasses two processes: the pretreatment of scrap and the smelting and refining of the material. Pretreatment includes sorting, processing, and cleaning of the scrap. The smelting and refining operation includes cleaning, melting, refining, alloying, and pouring of aluminium recovered from scrap. (Cora and Hung 2001).

Figure 3: The Aluminium Smelting Process – Flow Sheet



Source: (Fundamentals of Aluminium Metallurgy, 2011)

The production of primary aluminium from bauxite ore requires substantial energy input, primarily during the electrolysis stage. The associated carbon emissions are determined mainly by the energy mix used—whether derived from fossil fuels or renewable sources. Consequently, CO_2 emissions from aluminium production vary significantly between countries, depending on the dominant energy infrastructure.

A product's overall carbon footprint is influenced by multiple factors, including the transportation distance of materials and finished goods, as well as the extent of recycling practices employed. Increasing the use of recycled aluminium can substantially reduce both energy consumption and carbon emissions compared to primary production. (Alu Pro Org., 2021).

The complete process for producing EN AW-5754 aluminium for mounting cups for aerosol valves comprises Bauxite mining, alumina production, electrolysis into aluminium, casting, rolling, splitting, and lacquering.

1.3. Aluminium Recycling

It is estimated that approximately 75% of all aluminium ever produced remains in use today. Recycling aluminium requires only about 5% of the energy needed for primary production. (Gautam, Pandey and Agrawal, 2017).

Although aluminium can theoretically be recycled indefinitely without any loss of quality, this is rarely achieved in practice. One key reason is the existence of up to 450 different aluminium alloys—combinations of aluminium with various other metals—that cannot be easily separated or converted into one another once mixed.

This wide variety of alloy compositions complicates closed-loop recycling systems, as post-consumer scrap from diverse applications is often blended into mixed-metal streams. As a result, a significant share of recycled aluminium undergoes downcycling, where it is reused in lower-grade applications rather than returned to its original high-performance form, thereby reducing overall material efficiency and sustainability potential.

However, this would be necessary because they have different properties and applications. Automotive aluminium, for example, has a high magnesium and zinc content, which makes the metal harder. On the other hand, beverage cans and cooking pots have a high manganese content, making the aluminium more heat-resistant and better protected against decomposition. Other alloys in aeroplanes are particularly elastic.

The fact that the individual metal mixtures cannot be separated from each other is not the only problem. All the different alloys usually end up in the same scrap heap, meaning they are all melted together in the recycling process. The new, melted aluminium must then either be diluted with pure aluminium so that it can continue to be used in various ways or for less demanding applications.

This so-called downcycling means that high-quality aluminium loses quality with every recycling step and has fewer possible applications. Some alloys can no longer be used for 95 per cent of aluminium applications. Precisely what the recycled aluminium can be used for also depends on the origin of the scrap. Some scrap heaps can be used for only 5% of applications, while others can be used for almost 100%. Overall, the more diverse the alloys and metals a product contains, the more challenging it is to recycle.

Due to these technical challenges, most of the aluminium scrap in Germany is processed into "unspecified cast aluminium", i.e., it is directly converted into aluminium at the end of the recycling chain.

In addition, four to five per cent of aluminium is lost through oxidation in recycling processes across all alloys. In the case of particularly sensitive alloys, as much as 20-25% of the material is lost.

Aluminium alloys are categorised using a four-digit numbering system, where the first digit denotes the alloy series. They typically consist of about 99.5% pure aluminium, with small quantities of manganese (Mn), magnesium (Mg), copper (Cu), silicon (Si), and zinc (Zn) added to enhance mechanical strength and impart specific physical or chemical properties.

The composition of these alloying elements significantly influences both the performance characteristics and recyclability of aluminium. While tailored alloy formulations enhance strength, corrosion resistance, and surface finish, they also complicate recycling processes and can increase the carbon footprint when different alloys are mixed, underscoring the importance of careful alloy selection and improved scrap segregation in sustainable aluminium manufacturing.

The 1xxx series, often referred to as “pure aluminium”, contains a minimum of 99% aluminium. Alloys in this series are characterised by excellent corrosion resistance and high electrical conductivity, making them suitable for applications such as aluminium foil, chemical tanks, and tubing.

The 2xxx series primarily uses copper as the main alloying element, which significantly enhances strength and hardness. Aluminium alloy 2024, for example, is widely utilised in the aerospace and aviation industries due to its high strength-to-weight ratio, though it offers lower corrosion resistance than purer grades.

In the 3xxx series, the principal alloying elements are manganese and, in some cases, magnesium. Alloy 3003 is commonly used for cooking utensils, while 3004 is a standard material for beverage cans, offering a good balance of strength and formability.

The 4xxx series uses silicon as the primary alloying element, lowering the melting point and improving fluidity. Alloy 4043 is frequently employed as a filler material for welding automotive and structural components.

The 5xxx series is based on magnesium as its main alloying element, providing excellent corrosion resistance and weldability. These alloys are widely used in the production of pressure vessels, storage tanks, marine components, transportation equipment, bridges, and building structures. Alloy 5182 is particularly notable for its use in beverage can lids due to its strength and formability.

The 6xxx series combines magnesium and silicon to form magnesium silicide, resulting in a versatile alloy with good strength, corrosion resistance, and extrudability. This series is predominantly used for truck and boat frames, as well as extruded aluminium profiles.

The 7xxx series employs zinc as the principal alloying element, producing robust materials such as alloy 7075, which is widely used in aircraft construction and other high-strength structural applications.

Finally, the 8xxx series encompasses alloys with various other elements, tailored for specialised industrial applications, including packaging materials and electrical conductors.

From a sustainability perspective, the wide diversity of alloy compositions presents both opportunities and challenges: while specific alloy formulations enable optimised performance for targeted applications, they also complicate recycling and remelting processes, often leading to downcycling and increased energy demand. Therefore, enhancing alloy standardisation and scrap-sorting technologies is essential to improve the circularity and carbon efficiency of aluminium use within the packaging and manufacturing industries. (Helmenstine, 2019)**.**

The "environmental impact" of aluminium depends, among other things, on where the aluminium is produced. Depending on the plant's technological status and the type of electricity used, aluminium's environmental footprint can vary significantly.

Improved sorting of aluminium alloys is essential to enhance recycling efficiency. Although aluminium is not inherently sustainable on average, its overall recycling rate could be significantly increased through better alloy separation and product designs optimised for recyclability.(Stacey and Cwningenpress, 2015)

Beverage cans serve as a good example of effective recycling: they are collected separately due to deposit systems and are composed of only two distinct alloys—one for the can body and another for the closure. This material simplicity enables efficient recycling without any loss of quality.

However, achieving a 100% recycling rate is not feasible. Some material losses inevitably occur during the recycling process, and a small proportion of primary aluminium must always be added to compensate for alloy variations and maintain the required material properties.(International Aluminium Organisation, 2009)

Consequently, integrating design-for-recycling principles and circular economy strategies into product development is critical. Simplifying alloy compositions, improving product labelling, and advancing sorting technologies can significantly reduce material losses and energy demand, thereby enhancing the overall resource efficiency and carbon performance of the aluminium packaging value chain. When comparing the environmental impact of aluminium, it is also worth looking at production. More CO2 equivalents are produced per kilogram of aluminium, more energy is consumed, and the soil becomes more acidic due to waste materials generated during the production of new aluminium and those resulting from recycling. Additionally, waste products are more hazardous to humans than other common metals, such as copper, zinc, nickel, iron, or chromium. However, silver, gold and platinum perform significantly worse than aluminium.

The mining of bauxite and the production of primary aluminium not only cause high CO2 emissions but can also damage the environment in other ways. In 2010, one of Europe's most prominent environmental disasters occurred in Hungary. A pool of waste material, known as red mud, burst into an aluminium smelter. (Tabereaux, 2010). In addition to iron compounds, which give the sludge its characteristic red colour, it also contains arsenic, lead, cadmium, chromium, vanadium, and mercury. Over a billion litres of toxic waste flooded villages, fields, and streams. The incident claimed ten lives, and 150 others were injured. Approximately 350 houses had to be demolished and rebuilt elsewhere due to arsenic contamination. The contaminated soil was laboriously removed and cleaned with special plants that absorb pollutants. Making the area habitable again costs around 130 million euros of taxpayers' money

1.4. Background and Significance

Previous research on aluminium sustainability has concentrated mainly on the automotive, aerospace, food and beverage sectors, with particular emphasis on aluminium can production. However, sustainable aluminium is also playing an increasingly important role in the aerosol packaging industry, especially in relation to aerosol valve fixtures, such as mounting cups. Despite its industrial relevance, the application of post-consumer recycled (PCR) aluminium in aerosol valve components remains underexplored in academic literature.

This study seeks to address a clear research gap by evaluating the environmental advantages, material availability, and practical feasibility of using recycled aluminium to produce mounting cups in the aerosol industry."

By integrating life cycle assessment (LCA) principles and sustainability-oriented material analysis, the research aims to contribute to the broader discourse on low-carbon manufacturing strategies and circular economy practices in the global aluminium packaging value chain.

The fascination of spray cans and aerosols:

In an aerosol can, the contents are protected from air and contamination by microorganisms. The spray can is a safe and hygienic form of packaging. Additionally, the product can be precisely dosed and finely distributed, enabling sparing use. Sprays enable economical, precise and drip-free application in hard-to-reach areas. Physics, chemistry, and technology are uniquely coordinated. The term aerosol describes a "solution" of non-gaseous substances in the air, e.g. the suspended state of many tiny particles in a gas (Industriegemeinschaft Aerosole e.V., no date)

Aerosols have a wide range of applications:

For cosmetics: hairspray, deodorant spray, shaving foam, depilatory mouse, mousse for hair colouring, body care foam

For the household: bathtub cleaner, shoe care spray, toilet foam cleaner, room fragrance spray, insect spray, oven cleaner, carpet foam cleaner, glass cleaner, ironing aid, car care spray

In the food sector: spray cream, decorative sprays for cakes and tarts, popcorn seasoning spray, avocado oil spray, butter spray, garlic mist, olive oil spray, and cooking oil.

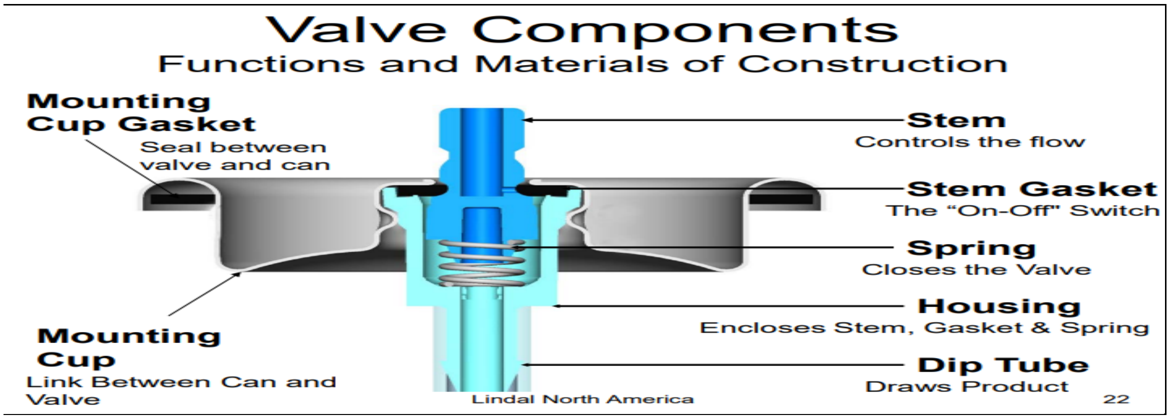
For the medical sector: disinfectant spray, asthma therapy spray, wart removal spray, cooling spray, wound closure spray

For the technical sector: paint and varnish sprays, rust protection and rust remover spray, spray adhesive, lubricant spray, Pu foam (construction foam)

For plants: plant protection spray, leaf shine spray

Within an aerosol can, the valve system is the most material-intensive component, with a greater diversity of parts and materials than the can body itself. It typically consists of aluminium, elastomers such as nitrile or butyl rubber, plastics, and metal springs. This material heterogeneity complicates both recycling and life-cycle assessment (LCA), as the separation and recovery of individual substances require additional sorting and treatment steps. Consequently, the environmental footprint of aerosol valves is influenced not only by the type of materials used but also by their design complexity, assembly methods, and the feasibility of material recovery within existing recycling systems.

Figure 4: Valve Components



Source: *(Daria, 2010)*

The starting point is a plastic tube that opens at the top. A spring is attached to the lower, closed side, which sits with the lower part of the tube in a plastic housing. The cup gasket rests on the edge of the can housing. The mounting cup presses this arrangement so tightly that only the tube moves, and the pressurised can is tightly closed.

Without pressure, the entire system cannot function. Physics, chemistry, and technology collaborate to achieve the correct pressure, which typically ranges from three to five bars for most sprays.

1.5. Mounting Cup Production

Mounting cups are manufactured using the deep-drawing stamping process, a forming technique that employs progressive tooling to shape the material. Deep drawing requires a material with high formability and a durable alloy composition that can withstand significant deformation without fracturing. The process parameters—such as material type, thickness, component size and geometry, and temperature—must be carefully controlled to ensure consistent quality and dimensional accuracy.

Owing to its technical complexity, deep drawing is generally more cost-intensive than conventional stamping. The specialised progressive compound tools required are significantly more expensive, and the process demands dedicated production facilities equipped with eccentric presses featuring vertical motion systems. When optimised, these presses can achieve production speeds of up to 2,000 strokes per minute, enabling high-volume output despite the greater tooling and equipment investment.

Deep drawing and stamping are distinct metal-forming processes used to manufacture components tailored to specific product requirements. Deep drawing is a sheet metal forming technique that delivers high dimensional accuracy and a smooth surface finish. At the same time, stamping involves striking a metal sheet with a die to achieve the desired shape. One of the main advantages of stamping is its efficiency and cost-effectiveness. Through careful tool design and process planning, manufacturers can optimise the use of progressive dies to minimise material waste and production scrap.

Precision deep-draw stamping combines these advantages by using a series of progressive dies that progressively stretch and form the material into its final geometry. This process enables the production of intricate and complex components with a high degree of accuracy and consistency. Deep-drawn products are typically more robust and durable than conventionally stamped parts, as they undergo greater mechanical stress and pressure during forming, which enhances their structural integrity. During the progressive die stamping process, a stock strip moves the part through a series of individual workstations, each performing a specific task on the workpiece, such as bending, punching, or coining. As the part moves through each station, it progressively takes on the desired size and shape. (Bhandari Ujjwal, 2024)

Aerosol products possess a distinctive performance profile and have maintained their popularity since their introduction to the market more than 70 years ago. They have become an integral part of modern consumer life, valued for their convenience, functionality, and versatility. Today, more than 200 categories of aerosol products exist, with applications that continue to expand across sectors. These include dry and wet sprays, creams, gels, and mousses, among others.

The European aerosol industry currently represents the most significant global producer, manufacturing over 5.5 billion units annually, reflecting both the sector's maturity and its continued relevance in everyday consumer and industrial applications.

Aerosol valves have several key features:

- Aerosols are a very efficient way of dispensing a product. The aerosol can be directed to the user's desired location and delivered with an accurate dose. There is very little wastage, and the product cannot spill.
- Aerosols are a hygienic dispensing mechanism. The aerosol is hermetically sealed, ensuring the product has a long shelf life and is not exposed to external sources of contamination (cloths, hands, air, etc.).

- In most product categories, aerosols are the most effective way of delivering the product. For example, aerosol technology allows the particle size of the spray to be controlled (essential for most aerosol products, such as air fresheners and insecticides) and the drying rate of the product to be controlled (a hairspray must stay wet long enough to coat the hair and then dry before it runs off).
- An aerosol valve operates as a non-visible component in an aerosol system but plays an essential role in keeping the container airtight, clean, and hygienic. It also regulates the flow of the product during use.
- The mounting cup is an integral part of aerosol valves, and it accounts for 50 % of the material cost of the complete valve. To produce aluminium mounting cups for aerosol valves, the aluminium alloys EN AW-5754 (European Standard) and EN AW-5052 (US Standard) are utilised.
- There is only a limited number of aluminium suppliers worldwide which can provide foil-coated or lacquered material slit into a special width. In addition to the rolling process and pre-treatment, the actual coating application (lacquer or foil), as well as the curing temperature and duration, are crucial to meeting production requirements.
- Various lacquer finishes are available: gold/gold, silver/silver, white/silver, Micoflex gold, or Micoflex silver. Standard thickness for mounting cup production is 0.41 and 0.38 mm, with material widths ranging from 141.5 to 231.5 mm, depending on the used press.

1.6. Pre- and Post- Consumer Aluminium

In the past years, the packaging industry and its key players (Aerosol Brand companies such as Unilever, Nestlé, L'Oréal, and Procter & Gamble) have shown increased interest in "green aluminium." However, further research is needed, specifically on this topic.

Key questions concerning the environmental advantages of incorporating post-consumer recycled (PCR) aluminium in the aerosol sector, particularly for mounting cup production, remain insufficiently explored. The purpose of this study is therefore twofold. The first objective is to assess the availability and suitability of high-quality primary aluminium for manufacturing mounting cups. The second objective is to evaluate the potential environmental benefits of increasing the proportion of post-consumer recycled aluminium in production processes.

The theoretical framework guiding this research is informed by a range of industry reports and publications from the aerosol packaging sector, providing the foundation for an evidence-based analysis of sustainability opportunities within aluminium component manufacturing. (FEA European Aerosol Federation, IGA German Aerosols, BAMA British Aerosol Association, Aerosol Europe Magazine, Spray Magazine, World Aerosols Magazine).

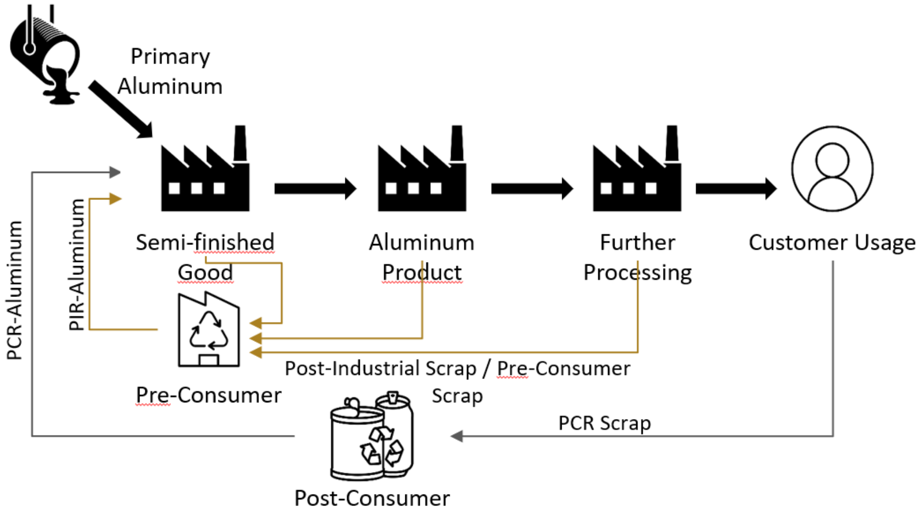
One of the central claims of this study is to investigate whether sufficient "PCR aluminium" is available in aluminium Grade EN AW-5754 required to produce mounting cups for aerosol valve fixtures. Current research indicates that aluminium is highly recyclable, but what does recycle content mean? ISO 14021 defines recycled content as including only pre-consumer and post-consumer recycled content. Recycled aluminium issued from process scraps generated during foil rolling and slitting does not fall within this definition. (GreenSpec, 2024)

A clear distinction exists between pre-consumer (post-industrial) and post-consumer waste. Pre-consumer waste refers to materials discarded during the manufacturing process, before reaching the end user. This category includes production scrap, such as paper trimmings, defective aluminum cans, and other off-specification materials that are often reintroduced into the production cycle.

In contrast, post-consumer waste comprises materials that have been used and discarded by end users, including individuals, households, and organisations. Increasingly, materials once considered waste are now recognised as valuable secondary raw materials, whose recovery and reuse contribute to the conservation of natural resources and support the transition toward a circular economy.

From a sustainability perspective, post-consumer recycled (PCR) aluminium holds greater environmental relevance than pre-consumer scrap, as it represents proper material recovery from the end-use phase, thereby reducing both landfill dependency and the carbon footprint associated with producing primary aluminium.

Figure 5: Aluminium Flow PIR/PCR



Source: *(GDA Gesamtverband der Aluminiumindustrie e.V., 2021)*

For some environmentalists, recycling pre-consumer waste on-site or collecting it for reprocessing is improper. The use of waste within a production line and its reintroduction into production is considered useful utilisation, rather than recycling.

Pre-consumer waste can be collected by type much more easily than post-consumer waste. Inclusions of foreign materials can render the waste useless for recycling.

The recycled content of individual alloys can subsequently be determined via volume flow measurement. This measurement is relatively time-consuming and does not indicate whether the specified amount of recycled material is present in strip XY or provide any information about its future usability. Alloy EN AW-5754 is used not only in the mounting cup sector but also in the construction sector.

Aluminium recycling represents one of the two fundamental pillars of global metal supply, alongside the production of primary aluminium through electrolysis. Because recycling offers significant energy and emission savings compared to primary production, maintaining a closed material loop and minimising metal losses throughout the product life cycle are key sustainability objectives. The most relevant indicator of this performance is the product's recycling rate at the end of its useful life.

However, the recycled metal content in individual products provides only a partial reflection of environmental performance, as it can fluctuate substantially depending on scrap availability, product mix, and the specific use of aluminium alloys and emulsions. In addition to primary metal sourced from smelters, manufacturers incorporate a variety of scrap types from both external and internal recycling streams. For example, in the production of the EN AW-5754 alloy, an average pre-consumer scrap content of approximately 70% was utilised during 2018 and the first half of 2019.

Looking ahead, increasing the proportion of post-consumer recycled (PCR) aluminium is essential to achieving true circularity within the aluminium value chain. Unlike pre-consumer scrap, PCR aluminium represents genuine material recovery from end-of-life products, thereby contributing more substantially to resource conservation, CO_2 reduction, and the long-term sustainability of aluminium-based manufacturing systems. (Karbach-Parr 2019).

The availability of aluminum as end-of-life scrap is inherently limited. To maintain the material within the circular economy, it is essential to ensure the efficient collection, sorting, and recycling of used products.

Enhancing collection infrastructure and consumer participation plays a pivotal role in this process, as higher recovery rates directly increase the supply of recyclable material, reduce dependency on primary aluminium, and support the overall resource efficiency and sustainability of the aluminium value chain. (European Aluminium Foil Association, 2019)**.** Metals are usually sorted in so-called materials recovery facilities (MRF). However, size matters during sorting. The relatively small aerosol product (mounting cup) may fall through the cracks in the sorting line and end up in landfills instead of being recycled.

To achieve mechanical corrosion performance, both the alloy and product specifications must be met, and primary aluminium must be added to the recycled metal to reduce impurity levels and achieve the desired properties. (Fundamentals of Aluminium Metallurgy, 2011)

The aerosol industry promotes its products as “recycling-friendly” because aerosol cans are mainly made of aluminium. The industry compares its products to beverage cans.

What is known is that aerosol cans do not have a recycling cycle similar to that of beverage cans. There is no system in place to recycle aerosol cans, separate the individual materials, and bring aluminium grade EN AW-5754 (used to produce mounting cups) back into the aluminium production cycle. Thus, no current system makes PCR aluminium available for reproduction. The research is based on mounting cups, an integral part of the aerosol valve fitted to the aerosol can.

1.7. Research Question/Hypothesis

Is there a benefit for the environment by lowering the carbon footprint of aluminium production for mounting cups when using first-class primary aluminium or a higher percentage of scrap (pre- and/or post-consumer recycled aluminium?

What is the problem to solve?

The challenge is to determine the most suitable approach to lower the carbon footprint of aluminium production for mounting cups.

What business segments are concerned?

The Aerosol Valve market (mounting cups): personal care, Beauty & Home, and pharmaceutical.

What are the known constraints?

Post-consumer recycled aluminium may not meet the market requirements of the standard used aluminium (grade EN AW-5754) or may not be available in sufficient quantity.

Must have / nice to have:

Significant carbon emission reduction for primary aluminium.

Availability of fully post-consumer recycled raw material (secondary aluminium)

Positive environmental and commercial impact.

The following Hypotheses guide this study:

- **H1:** The carbon footprint of aluminium production can be reduced using higher-quality primary aluminium with improved process efficiency and lower emission intensity.

- **H2:** The carbon footprint of aluminium production will decrease with an increased use of scrap material, including post-industrial (PIR) and post-consumer recycled (PCR) aluminium, provided that enough PCR aluminium in alloy grade EN AW-5754—the standard alloy used for mounting cup production—is available.

- **H3:** The availability of PCR aluminium for aerosol valve manufacturing can be enhanced if alloy grade EN AW-3104 is determined to be technically suitable for mounting cup production, based on both theoretical analyses and practical testing results.

To test the proposed hypotheses, the following research steps are required:

- Step 1: Evaluation of first-class primary aluminium. Since the carbon footprint of primary aluminium production varies depending on the energy source used, the first stage of the study involves examining the environmental advantages of employing low-carbon (“greener”) primary aluminium for mounting cup production.

- Step 2: Assessment of post-consumer recycled (PCR) aluminium. The second stage focuses on the availability and feasibility of using PCR aluminium in alloy grade EN AW-5754. This includes investigating existing sorting systems for aerosol cans, identifying potential collection channels, and determining sources of high-quality PCR aluminium suitable for manufacturing applications.
- Step 3: Testing the suitability of alloy EN AW-3104. The third stage examines the modification and performance testing of aluminium grade EN AW-3104, currently used as the standard material for beverage cans. Collaboration with a leading aluminium supplier could enable the production of a modified version of EN AW-3104, potentially suitable for mounting cup applications.

An essential performance requirement is that the aluminium must withstand internal pressures of up to 50 bar in aerosol cans. Preliminary theoretical analyses indicate that EN AW-3104 may meet these conditions, although practical validation is still required.

If proven viable, the adoption of EN AW-3104 could transform the global aerosol packaging market, enabling the use of a standardised alloy with high PCR availability. Furthermore, the results of this study could serve as a benchmark for related industries, such as the pharmaceutical (ferrules) and cosmetic (closures and caps) sectors, which similarly rely on specialised aluminium grades with restricted PCR accessibility.

1.8. Objectives and Aims

This research aims to examine the environmental and economic advantages of utilising recycled aluminium in manufacturing processes. While extensive studies exist within the beverage can industry, a notable research gap remains concerning niche applications, such as mounting cups for aerosol valves. The primary objective of this study is to evaluate whether the use of 100% post-consumer recycled (PCR) aluminium in the production of mounting cups can deliver measurable environmental benefits. Ultimately, the research seeks to reduce the carbon footprint associated with aluminium aerosol packaging and to contribute to the development of more sustainable material sourcing strategies within the industry.

Specific Objectives

To achieve the main objective, the following goals are:

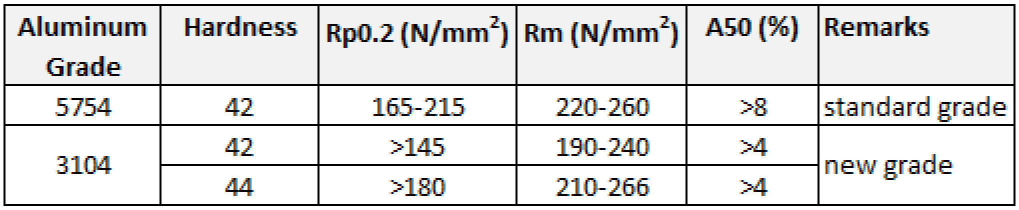
To determine the carbon footprint of primary aluminium produced in different countries using different power sources. Identify the material with the lowest carbon footprint. (Raabe et al. 2022).

- To quantify the global annual aluminium consumption associated with mounting cup production and to evaluate the corresponding CO_2 emission levels resulting from this aluminium usage. Furthermore, to analyse how the emission profile changes when increasing the proportion of low-carbon primary aluminium or post-consumer recycled (PCR) aluminium in production.

- To assess the availability of PCR aluminium in alloy grade EN AW-5754 and identify feasible pathways to secure sufficient supply. In addition, to define alternative materials or process steps that can be produced in adequate quantities to meet industry requirements.

- To conduct experimental test runs using alternative aluminium grades, with particular focus on EN AW-3104, to validate its technical suitability as a potential substitute for the current standard alloy EN AW-5754. Statistical evaluations will be conducted to verify the material's performance and ensure alignment with production specifications.

Table 1: Comparison of mechanical values of different aluminium grades



Aluminum Grade	Hardness	Rp0.2 (N/mm^2)	Rm (N/mm^2)	A50 (%)	Remarks
5754	42	165-215	220-260	>8	standard grade
3104	42	>145	190-240	>4	new grade
	44	>180	210-266	>4	

Source: *(Aditya Birla Novelis, 2022)*

Specific Aims

This research aims to reduce CO_2 emissions associated with the production of aluminium for mounting cups used in aerosol valves. Leading aluminium suppliers—including Aludium, Aditya Birla Novelis, Laminazione Sottile SpA, Arconic Products, Golden Aluminium, and Lidao—have reported an insufficient supply of post-consumer recycled (PCR) material to meet the growing demand from aluminium converters. The standard alloy currently in use for mounting cup production is EN AW-5754. Therefore, the first objective of this study is to assess the market availability of PCR aluminum in grade EN AW-5754.

A potential alternative approach involves evaluating the feasibility of substituting EN AW-5754 with EN AW-3104, a more widely available aluminium grade with a higher share of post-consumer scrap (PCR). EN AW-3104, commonly used in the beverage can industry, exhibits similar mechanical and forming properties to EN AW-5754. Consequently, increasing its utilisation in mounting cup production could enhance PCR availability and contribute to further reductions in the industry's carbon footprint. By adopting EN AW-3104 aluminium, the aerosol valve industry could increase its use of post-consumer recycled material in mounting cup manufacturing, thereby advancing sustainability goals and reducing CO_2 emissions within the aluminium value chain

In summary, these research stages directly support the study's overarching objective: to quantify and enhance the environmental performance of aluminium packaging through the integration of post-consumer recycled materials and the optimisation of alloy selection. By combining life cycle assessment (LCA) with practical industry data, this research aims to contribute to reducing CO_2 emissions, promoting circular material flows, and advancing sustainable manufacturing practices within the global aluminium value chain.

Adopting aluminium grade EN AW-3104 could provide a practical solution for the aerosol valve industry to incorporate post-consumer recycled (PCR) aluminium into mounting cup production, thereby significantly reducing CO_2 emissions associated with primary aluminium manufacturing. Beyond its environmental benefits, this substitution would also strengthen circular economy practices, enhance supply chain resilience, and support the industry's transition to more sustainable, resource-efficient production systems.

1.9. Sources of Data Collection and Data Management

Further research on the use of post-consumer recycled (PCR) aluminium to produce mounting cups in aerosol valves is required, as existing studies on this topic remain limited. An exploratory research approach is therefore applied to address this gap.

The primary data source will consist of industry publications, including press releases and technical articles from aerosol trade journals, as well as reports and internal research conducted by aluminium producers, aerosol valve manufacturers, and end users. The secondary data source will draw upon existing studies and datasets related to CO_2 emission rates and the carbon footprint of aluminium production.

All collected information will be systematically analysed to determine the validity of the research hypotheses, assessing whether they can be confirmed or refuted based on available empirical and industry evidence.

The following hypotheses were formulated to address the key research objectives of this study, which aim to evaluate the environmental benefits and material feasibility of integrating post-consumer recycled (PCR) aluminium into mounting cup production for aerosol valves. Each hypothesis is linked to a specific validation method, combining theoretical analysis, industry data evaluation, and practical testing to ensure a comprehensive and evidence-based approach.

Figure 6: Hypothesis – Description and Validation Method

Hypothesis	**Description**	**Validation Method**
H1	The carbon footprint of aluminium production can be reduced by using high-quality, low-emission primary aluminium sourced from producers that utilise cleaner, more efficient energy inputs.	Comparative analysis of CO_2 emission data from different primary aluminium producers; evaluation of energy mix and regional emission factors (LCA-based assessment).
H2	The carbon footprint of aluminium production decreases with a higher proportion of post-consumer recycled (PCR) aluminium, provided that sufficient PCR aluminium in alloy grade EN AW-5754—the standard material for mounting cup production—is available.	Analysis of CO_2 emission reductions based on varying PCR input ratios; assessment of PCR EN AW-5754 availability through industry reports, supplier data, and recycling statistics.
H3	The availability of PCR aluminium can be enhanced if the alloy grade EN AW-3104 is proven technically suitable for mounting cup manufacturing.	Laboratory and industrial test runs of EN AW-3104 for mounting cup applications; comparison of mechanical and forming

Hypothesis	Description	Validation Method
	Theoretical analyses indicate potential feasibility, but practical testing is required to confirm its performance.	properties against EN AW-5754; evaluation of PCR availability in beverage-can recycling streams.

Source: Created by the author

The outcomes of these hypotheses will provide a foundation for evaluating the environmental, technical, and economic implications of using post-consumer recycled aluminium in the manufacture of aerosol valves. The resulting insights will inform a comparative life-cycle assessment (LCA) to quantify potential reductions in CO_2 emissions and energy demand across different aluminium sourcing scenarios. Furthermore, the findings will support the formulation of industry-specific recommendations to enhance supply chain sustainability, material circularity, and low-carbon innovation across the global aluminium packaging sector.

1.10. Research Significance

As limited research exists on aluminium mounting cups used in aerosol valves, the industry's prevailing assumption is that incorporating a greater share of post-consumer recycled aluminium will significantly reduce CO_2 emissions. This research provides an essential empirical assessment to confirm or refute this hypothesis and to clarify the true environmental potential of PCR aluminium within the aerosol sector.

CHAPTER II:

REVIEW OF LITERATURE

2.1. Theoretical Review

A preliminary review of the literature indicates that previous research has predominantly focused on the automotive, aerospace, and food and beverage sectors, where aluminium is widely used for lightweight structures and packaging such as beverage cans. However, the role of sustainable aluminium within the packaging industry—particularly in aerosol valve fixtures and components such as mounting cups—has received comparatively limited academic attention. This gap is noteworthy given the growing importance of environmental performance, material efficiency, and carbon reduction in global manufacturing. Understanding how post-consumer recycled (PCR) aluminium can be integrated into these specialised applications is therefore crucial to advancing sustainability practices, circular economy principles, and low-carbon innovation within the aluminium packaging value chain. In the aerosol and pharmaceutical packaging industries, the valve assembly is attached to the aerosol can for regulating product discharge. The mounting cup, an integral component of the valve, functions as the closure element that secures the valve to the can. The valve system itself comprises multiple parts made from various materials, including aluminium, nitrile or butyl rubber, plastics, and metal springs.

Among these materials, aluminium plays a significant role due to its strength, corrosion resistance, and recyclability. However, the increasing demand for low-carbon and circular production models has highlighted the need for more sustainable aluminium sourcing, particularly through the integration of post-consumer recycled (PCR) material into valve and mounting cup manufacturing.(Daria 2010).

Primary data for this research are derived from company reports of aluminium manufacturers, conference proceedings, and government publications. Secondary data are obtained from peer-reviewed journals, industry analyses, and academic textbooks, while tertiary sources, such as dictionaries and encyclopaedias, provide reliable contextual information on general concepts.

The literature review is organised into three key thematic areas to identify and evaluate relevant sources for this study:

- Manufacturing and processing of aluminium – providing foundational knowledge on industrial production methods, energy use, and material properties.
- Aluminium recycling – exploring general principles, technologies, and environmental implications associated with recycling processes.
- Aluminium recycling in the aerosol industry – focusing on material recovery, process challenges, and sustainability initiatives specific to aerosol packaging applications.

Investigating the feasibility of using post-consumer recycled (PCR) aluminium for mounting cup production offers valuable insights for global aerosol valve suppliers. The discussion emphasises two central sustainability strategies:

a) the transition to renewable (“green”) energy in primary aluminium production, and

b) the expanded use of recycled aluminium to reduce dependence on primary material and lower the industry’s carbon footprint.

The collected literature will be systematically analysed using a thematic and comparative approach to identify trends, knowledge gaps, and interdependencies between environmental performance, material selection, and recycling practices. This structured analysis will form the foundation of the theoretical framework, guiding the empirical assessment and validation of the study’s hypotheses.

Aluminium Production

After mining and refining, the primary aluminum is subsequently melted, slit, and lacquered as part of the downstream production process. The ratio of primary to recycled aluminum incorporated into final products is determined by the individual smelters, depending on their sourcing strategies and material availability.

The following table provides an overview of worldwide aluminium production volumes, distinguishing between the production country composition.

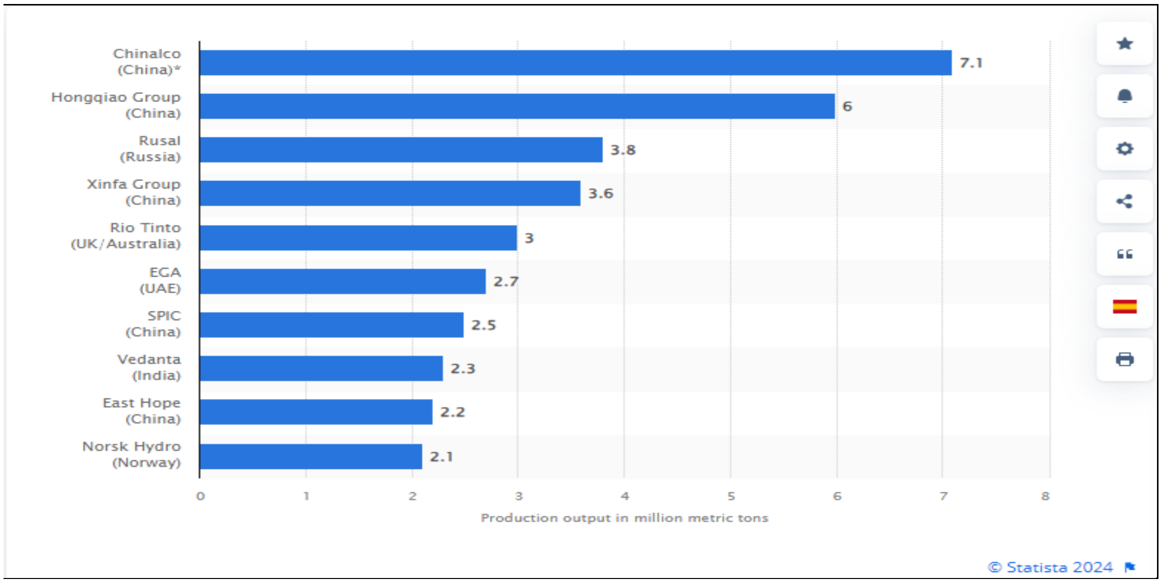
Figure 7: Primary Aluminium Production (thousand metric tons of aluminium

Period	Africa	North America	South America	Asia (ex China)	Western & Central Europe	Russia & Eastern Europe	Europe (inc Russia)	Oceania	Gulf Cooperation Council	China (Estimated)	Estimated Unreported to IAI	Total	Daily Average
2025	* 1,211	2,952	1,157	3,630	-	-	5,259	1,397	4,602	33,023	1,882	55,113	201.9
2024	1,576	3,983	1,521	4,812	2,828	4,168	-	1,863	6,346	43,396	2,516	73,009	199.5
2023	1,594	3,897	1,466	4,673	2,713	4,016	-	1,884	6,217	41,666	2,590	70,716	193.7
2022	1,620	3,743	1,288	4,591	2,913	4,081	-	1,843	6,074	40,430	2,455	69,038	189.1
2021	1,590	3,880	1,163	4,499	3,329	4,139	-	1,888	5,889	38,837	1,878	67,092	183.8
2020	1,605	3,976	1,006	4,140	3,334	4,153	-	1,912	5,833	37,337	2,029	65,325	178.5
2019	1,643	3,809	1,079	4,395	3,449	4,157	-	1,916	5,654	35,795	1,760	63,657	174.4

Source: (International Aluminium Org. n.d.)

The table below presents the leading global producers of primary aluminium in 2022, organised by annual production output.

Figure 8: Leading Global Aluminium Production Countries



Source: (Statista, 2023)

Aluminium is an ideal material for the circular economy due to its strength, low weight, durability, and its ability to be infinitely recycled without loss of quality when properly processed. Many aluminium producers now offer recycled aluminium as a more sustainable alternative to primary material, aligning with the growing demand for environmentally responsible solutions. (Speira GmbH, 2025)

From an energy and emissions perspective, recycling aluminium can achieve savings of up to 95% compared with producing primary aluminium, making it one of the most effective strategies for reducing the industry’s overall carbon footprint. (Hydro.com, 2021)

Table 2: Global Footprint of Aluminium Production

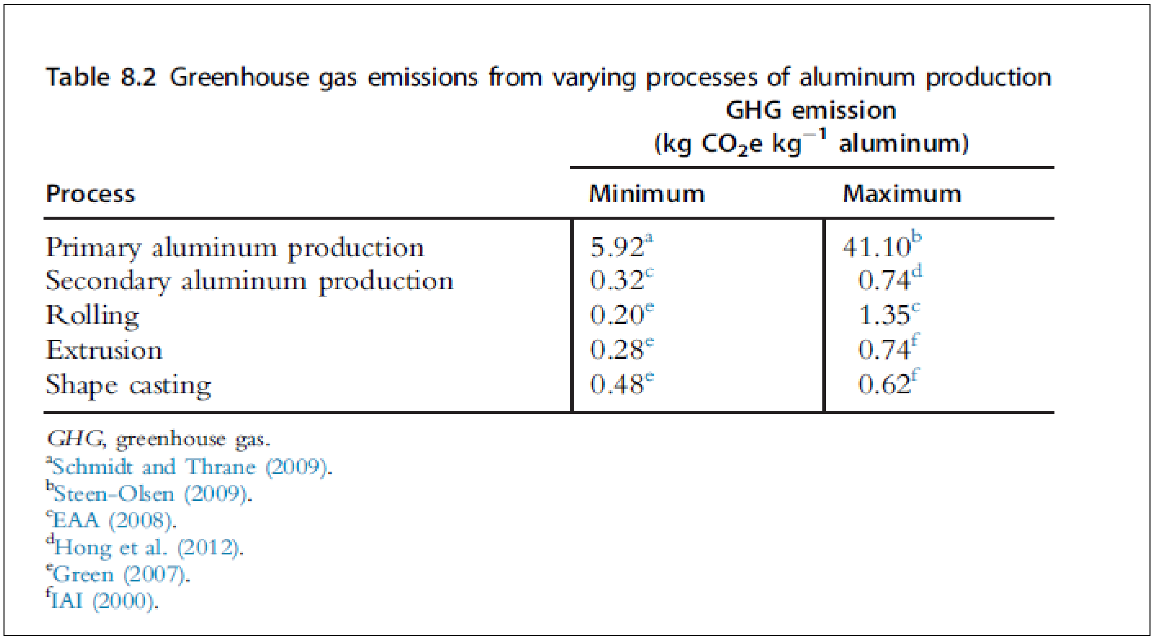


Table 8.2 Greenhouse gas emissions from varying processes of aluminum production

Process	GHG emission ($kg\ CO_2e\ kg^{-1}$ aluminum) Minimum	GHG emission ($kg\ CO_2e\ kg^{-1}$ aluminum) Maximum
Primary aluminum production	5.92[a]	41.10[b]
Secondary aluminum production	0.32[c]	0.74[d]
Rolling	0.20[e]	1.35[c]
Extrusion	0.28[e]	0.74[f]
Shape casting	0.48[e]	0.62[f]

GHG, greenhouse gas.
[a] Schmidt and Thrane (2009).
[b] Steen-Olsen (2009).
[c] EAA (2008).
[d] Hong et al. (2012).
[e] Green (2007).
[f] IAI (2000).

Source: (Gautam et al. 2017)

However, not all recycling is equal in terms of its environmental impact – it depends on where the material comes from and whether it has had a useful life in a product before. What makes it complicated is that aluminium companies use different methods to calculate the environmental impact of their materials. There is no common standard to guide buyers, designers, architects, and engineers on the sustainability of recycled aluminium. To understand which type of recycled aluminium is better for the environment, it is essential to know where the material originates. The higher the recycled post-consumer content in aluminium, the lower the carbon footprint. (Hydro.com, 2021)

This research aims to generate practical insights for valve manufacturers by examining the feasibility and advantages of incorporating PCR aluminium into production processes. It is also essential to distinguish between the recycling pathways of beverage cans and aerosol cans, as approximately 50% of all aerosol cans worldwide are manufactured from aluminium, representing a significant opportunity for carbon reduction and material circularity.(HCPA Organisation 2022).

In this context, the study will analyse data from both the beverage can and aerosol packaging industries to better understand the differences in alloy composition, recycling rates, and material recovery efficiency. Emphasis will be placed on mounting cups as a representative component within the aerosol valve system, given their complex production process and specific material requirements. By comparing the availability, quality, and environmental performance of post-consumer recycled (PCR) aluminium in these two sectors, the research aims to identify practical pathways for integrating high-PCR alloys into aerosol valve manufacturing.

This comparative approach will also contribute to a broader understanding of how industrial design choices, recycling infrastructure, and supply chain management influence the carbon footprint of aluminium products—providing a foundation for evidence-based recommendations for both manufacturers and policy makers within the aluminium packaging value chain.

For the aerosol industry, implementing a circular economy approach presents a considerable challenge due to the multi-material composition of aerosol products. Since aerosols are manufactured using various materials—such as aluminium, stainless steel, glass, plastics, and chemical components (including propellants of both natural and synthetic origin)—adequate segregation and sorting are essential prerequisites for successful recycling and further material recovery.

In 2018, more than 5.5 billion aerosol units were produced in Europe, while global production exceeded 18 billion units. Of these, approximately 55% were made of aluminium, and around 44% consisted of steel, with glass and plastic containers accounting for less than 1%. Most aluminium aerosol cans incorporate an aluminium mounting cup as part of their valve system. Despite this, recycling rates remain very low: in the United States, only about 1% of aerosols are correctly and safely recycled, and in Europe, the proportion is even lower, as recycling of aerosol waste is not yet a widely established practice. (Niemiec et al. 2021).

Within the industry, post-consumer recycled (PCR) material refers to aluminium collected from end users, sorted, processed, and reintroduced into production as a secondary raw material. In the context of mounting cup manufacturing, this requires that enough high-quality PCR aluminium in the appropriate alloy grades be readily available at the production sites and through the respective aluminium suppliers to ensure continuous and reliable processing.(Georges 2022).

The European Packaging and Packaging Waste Directive (PPWD)—or comparable regulatory frameworks—must provide a clear definition of recyclability and the associated recycling processes. It is essential to distinguish between theoretical recyclability, which refers to the material's potential to be recycled, and practical recyclability, which depends on whether the process is technically feasible, economically viable, and capable of producing a material output suitable for industrial reuse, such as in the production of mounting cups. At present, the availability of post-consumer recycled (PCR) aluminium meeting the required quality and alloy specifications for mounting cup manufacturing remains significantly limited, posing a significant constraint to the broader adoption of circular production practices within the aerosol valve industry. (D'haese, 2022)

Aluminium is the second most widely used metal in modern society, with applications spanning packaging, construction, transportation, and architecture. However, because of its high energy requirements during extraction and production, recent literature reflects a growing research interest in aluminium recycling, particularly within the aerosol packaging industry. Numerous studies confirm that aluminium is a highly recyclable material; yet, most existing research has been conducted within the beverage can sector, leaving smaller niche applications, such as aerosol packaging, relatively underexplored.

A substantial gap remains between aluminium's recyclable potential and the actual recycling rates achieved in the aerosol industry. In both the United Kingdom and the United States, several initiatives have been launched to raise public awareness, improve can emptying practices, and enhance sorting and material recovery processes, thereby promoting a more effective recycling system for aerosol products. (Okey, 2022a)

Recycled content refers to the proportion of a product’s materials that have been diverted from the solid waste stream and reintroduced into the production cycle. When such materials are recovered during the manufacturing process, they are classified as pre-consumer recycled content (also referred to as post-industrial material). In contrast, materials recovered after a product has been used and discarded by end users are defined as post-consumer recycled content (PCR).

Distinguishing between these two categories is essential for accurate carbon accounting and life cycle assessment (LCA). While both contribute to waste reduction, pre-consumer recycling typically involves materials that have never entered the consumer market and, therefore, only partially reduce environmental impact. Post-consumer recycling, by contrast, represents true material recovery from end-of-life products, offering greater potential for reducing CO_2 emissions, conserving resources, and advancing the principles of the circular economy within the aluminum industry. (Kubba, 2017)

Difference between post-consumer and post-industrial waste

Materials once regarded merely as waste are now increasingly recognised as valuable secondary raw materials, whose reuse and recovery contribute to the conservation of natural resources. Post-consumer waste (PCR) originates from end users, such as individuals, households, and offices, whereas post-industrial waste (PIR) is generated during manufacturing or production processes.

Some environmental scholars and practitioners argue that post-industrial waste, when reused or reprocessed on-site, does not constitute true recycling, as it has not exited the production system. Instead, such internal reuse is often classified as a beneficial use or process optimisation, rather than recycling in the strict environmental sense.

From an operational perspective, post-industrial waste can generally be collected, sorted, and reintroduced into production more easily than post-consumer waste, since it is typically cleaner and more homogeneous. In contrast, post-consumer materials often contain foreign contaminants that can compromise recyclability if effective separation and purification are not achieved. Despite growing global demand, there are still very few specialised companies capable of recycling aerosol products, further limiting the availability of high-quality PCR aluminium for reuse in the industry.

Addressing this limitation is crucial for advancing the use of PCR aluminium in mounting cup production, thereby supporting circular material flows, reducing CO_2 emissions, and enhancing sustainability performance across the aerosol packaging value chain.

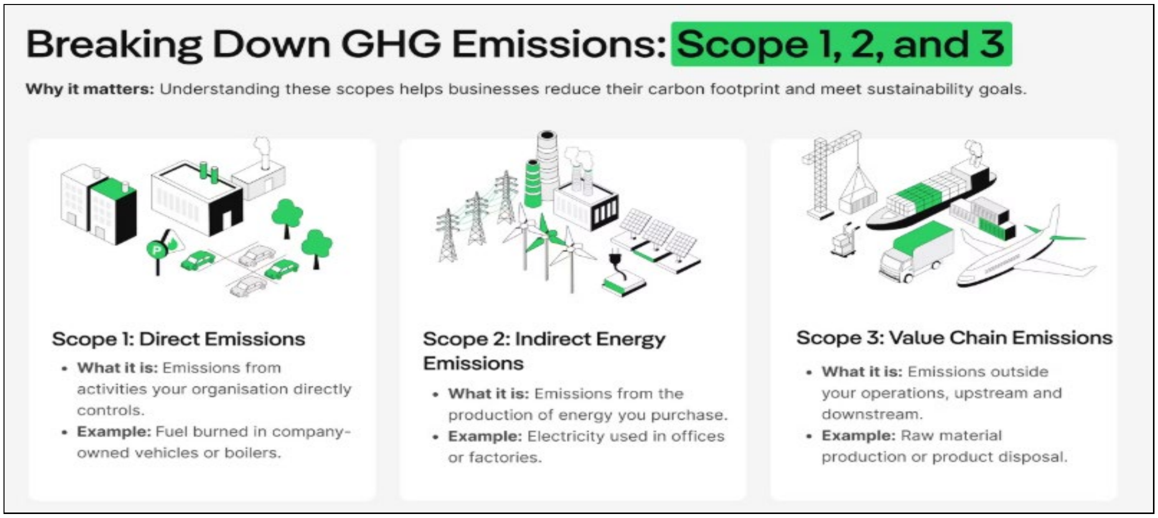
The standard recycling process for aerosol containers involves placing the cans into a hopper system housed within an airtight, inert chamber. The operation can be carried out by a single operator, with minimal pre-sorting required apart from the removal of large metal fragments and other unwanted foreign materials.

During processing, the aerosol cans are compressed under vacuum conditions into dry metal briquettes suitable for recycling. The valve assembly, including the mounting cup, is not typically separated from the can before compression. (McKay, 2024)

While this approach is efficient for volume reduction and handling, it can lead to material contamination and alloy mixing, as the different metals and non-metallic components from the valve and mounting cup become incorporated into the recycled material stream. This reduces the purity and quality of the recovered aluminium, thereby limiting its suitability for high-grade applications such as mounting cup production.)

2.2. Conceptual Frameworks

Figure 9: Breaking Down GHG Emissions



Breaking Down GHG Emissions: Scope 1, 2, and 3

Why it matters: Understanding these scopes helps businesses reduce their carbon footprint and meet sustainability goals.

Scope 1: Direct Emissions

- **What it is:** Emissions from activities your organisation directly controls.
- **Example:** Fuel burned in company-owned vehicles or boilers.

Scope 2: Indirect Energy Emissions

- **What it is:** Emissions from the production of energy you purchase.
- **Example:** Electricity used in offices or factories.

Scope 3: Value Chain Emissions

- **What it is:** Emissions outside your operations, upstream and downstream.
- **Example:** Raw material production or product disposal.

Source: (Anderson, 2025)

2.2.1. Scope 1, 2 and 3 Carbon Emissions

Reducing CO_2 emissions has become an essential economic and environmental priority for all organisations. Carbon dioxide accounts for approximately 81% of total greenhouse gas (GHG) emissions, with industrial and corporate activities as the primary contributors. The remaining share of global GHG emissions consists of methane (10%), nitrous oxide (7%), and fluorinated gases (3%). (Anderson, 2025)

Organisations are required to monitor and report their CO_2 emissions, as this represents the first and most crucial step towards effective reduction strategies. To achieve this, companies categorise their carbon footprint into Scope 1, Scope 2, and Scope 3 emissions.

Scope 1 emissions encompass the direct release of greenhouse gases (GHGs) resulting from activities that occur within an organisation’s own operations. These are emissions produced from company-owned or controlled sources and are released into the atmosphere as a direct consequence of internal business activities. Scope 1 emissions are typically divided into four categories:

Stationary combustion: Emissions generated from fixed fuel and heating sources. All fuels that emit GHGs must be included under this category.

Mobile combustion: Emissions produced by vehicles owned or controlled by the company (e.g., cars, vans, or lorries). With the increasing adoption of electric vehicles (EVs), a portion of fleet-related emissions may shift to Scope 2.

Fugitive emissions: Unintentional leaks of greenhouse gases from equipment such as refrigeration and air-conditioning systems. These refrigerant gases often have a significantly higher global warming potential than CO_2.

Process emissions: Gases released during industrial and on-site manufacturing activities, including CO_2 generated from chemical reactions, factory exhaust, and production processes.(World Resources Institute, 2023)

Scope 2 emissions refer to indirect emissions resulting from the generation of purchased energy from an energy supplier. All greenhouse gas emissions are released into the atmosphere through the consumption of purchased electricity, steam, heating and cooling. For most organisations, electricity is the primary source of Scope 2 emissions. In simple terms, the energy consumed falls into two scopes: Scope 2 covers the electricity end users consume. Scope 3 includes energy consumed by utilities during transmission and distribution. (World Resources Institute, 2023)

Scope 3 emissions include all indirect greenhouse gas emissions—other than those classified under Scope 2—that occur throughout an organisation's entire value chain. These emissions originate from both upstream and downstream activities related to the company's operations, products, and services. According to the Greenhouse Gas (GHG) Protocol, Scope 3 emissions are categorised into 15 distinct groups that encompass all relevant sources across the corporate value chain. (GHG Greenhouse Gas Protocol, 2025)

Upstream activities within Scope 3 emissions are categorised into several distinct areas. For many organisations, business travel represents one of the most significant sources of emissions to be reported, encompassing air travel, rail, metro and tram journeys, taxis, buses, and business kilometres travelled in private vehicles. Emissions generated by employee commuting—travelling to and from the workplace—must also be accounted for. These emissions can be mitigated by promoting public transport, car-sharing initiatives, and remote or hybrid working models.

Waste generated in operations includes all waste sent to landfill sites or wastewater treatment facilities. The decomposition and processing of such waste emit methane (CH_4)

and nitrous oxide (N_2O), both of which have higher global warming potentials than carbon dioxide (CO_2).

Purchased goods and services encompass all upstream (cradle-to-gate) emissions associated with the production of goods and services acquired by the organisation within a given reporting year. It is helpful to differentiate between production-related purchases—such as materials, components, and parts—and non-production-related purchases, including office furniture, supplies, and information technology services. (GHG Greenhouse Gas Protocol, 2025)

Transport and distribution emissions occur in the upstream (suppliers) and downstream (customers) elements of the value chain. These include emissions from land, sea, and air transport, as well as emissions associated with storage by third parties.

Fuel- and energy-related activities encompass all indirect emissions resulting from the production and supply of fuels and energy purchased and consumed by the reporting organisation during the accounting year, which are not already accounted for under Scopes 1 or 2.

Capital goods refer to long-lived assets that companies utilise to manufacture products, deliver services, or store, distribute, and sell goods. Typical examples include buildings, vehicles, and machinery. Within the framework of Scope 3 carbon accounting, organisations should not depreciate, discount, or amortise the emissions associated with the production of these capital goods over time. Instead, the total cradle-to-gate emissions resulting from the manufacture of purchased capital goods must be fully accounted for in the reporting year in which the purchase occurs. (GHG Greenhouse Gas Protocol, 2025)

Investment-related emissions are primarily relevant to financial institutions. In accordance with Greenhouse Gas (GHG) accounting standards, investment activities are classified into four main categories: equity investments, debt investments, project finance, and managed investments, along with client services associated with these activities.

Franchise-related emissions occur when organisations operate under a licence agreement to sell or distribute another company's goods or services within a specific territory. These emissions must be considered where the franchising arrangement influences operational control or contributes to the overall carbon footprint.

Emissions from products in use relate to goods sold to consumers that continue to generate emissions during their operational life. This category quantifies the 'in-use' phase emissions of a product, which can vary considerably depending on product type and lifespan. For example, an iPhone may take several years of use to emit an amount of CO_2 equivalent to that generated during its manufacturing phase.(GHG Greenhouse Gas Protocol, 2025)

End-of-life emissions refer to products that have been sold to consumers and are reported in a manner similar to waste generated during operations. Organisations are required to evaluate how their products are disposed of at the end of their useful life; however, this assessment can be challenging, as disposal practices are primarily determined by consumer behaviour. This consideration highlights the importance of designing products with recyclability in mind, thereby facilitating material recovery and reducing landfill waste.(International Aluminium Institute, 2022)

2.2.2. Availability of PCR aluminium grade EN AW-5754

A review of the existing literature reveals a substantial number of studies addressing the topic of aluminium recycling. One notable initiative is led by Alupro, the Aluminium Packaging and Recycling Organisation in the United Kingdom, which launched a national campaign to raise awareness of aerosol recycling. The initiative comprises a three-step programme focused on:

a) educating consumers on correct recycling practices,

b) establishing a baseline recycling rate, and

c) developing a roadmap to achieve higher collection and recycling targets.

The programme, which commenced in 2022 and is scheduled to run until the end of 2024, reflects a growing commitment to enhancing aluminium recovery rates and public engagement. However, further improvements in recycling infrastructure and consumer awareness remain essential. The United Kingdom, as the second-largest aerosol market in Europe, is making significant progress towards the development of a more efficient and sustainable aerosol recycling system. (World Aerosols, 2023)

Similar initiatives have been introduced across Europe and the United States to improve aluminium recycling rates and promote circular economy practices within the aerosol sector. In the European Union, programmes supported by organisations such as the European Aluminium Association (EAA) and Metal Packaging Europe (MPE) aim to standardise collection systems, harmonise recycling definitions, and enhance traceability across member states. These initiatives focus on developing closed-loop recycling systems that allow recovered aluminium from packaging—such as beverage and aerosol cans—to be reprocessed into new, high-grade products.

In the United States, the Can Manufacturers Institute (CMI) and the Aluminium Association have launched campaigns to increase consumer participation and improve material recovery rates through public awareness, deposit-return schemes, and investment in advanced sorting technologies. Collectively, these efforts reflect a global movement towards achieving higher recycling efficiency, lower carbon emissions, and greater material circularity in the aluminium packaging industry.

The beverage can, building and construction, and automotive industries have already established closed-loop recycling systems that enable the recovery and reuse of post-consumer aluminium. PreZero Pyral, a specialist in household waste recycling, employs a highly complex and technologically advanced process to sort aluminium scrap into distinct alloy groups. This precision sorting prevents the mixing of high-grade and lower-grade aluminium, highlighting the technical challenges involved in maintaining alloy purity during recycling. However, it is essential to note that none of these recovered alloys are suitable for producing aluminium alloy EN AW-5754, the standard grade required for mounting cup manufacturing.

In the United Kingdom, Red Industries is one of the few companies specialising in aerosol can recycling. During processing, the aerosol cans are compressed into briquettes, and the valve assemblies are mechanically separated and subsequently treated as residual waste. As a result, material recovery is focused primarily on the can body, while the aerosol valve—including the mounting cup—is excluded from aluminium recycling streams. This underscores that adequate material segregation remains a critical prerequisite for enabling recycling and reprocessing of aluminium suitable for mounting cup production. (Clews, 2022) Recycle Aerosol US has acknowledged that the aerosol industry is widely recognised for its insufficient recycling performance. At present, there are no dedicated public collection systems in place for the systematic recovery of used aerosol cans. Furthermore, there is limited information available regarding the separation of aerosol valves from can bodies, as well as the ability to distinguish between different aluminium alloys—specifically, between the 3xxx-series alloys typically used for aerosol cans and the EN AW-5754 alloy required for mounting cup production (Okey, 2022b)**.** Aerosol recycling presents a distinct set of challenges compared with conventional metal packaging. In addition to recovering the metal container and its various valve components, two further elements must be addressed: the residual propellants and the remaining liquid contents. Effective management of these factors requires a comprehensive and integrated strategy for the end-of-life recycling of aerosol products.

The presence of pressurised gases and chemical residues significantly increases the complexity of the recycling process, as these components must be safely neutralised or extracted before the materials can be sorted, separated, and reprocessed. Consequently, the recovery efficiency of high-grade aluminium alloys used in aerosol valves and mounting cups remains limited, underscoring the need for technological innovation and design-for-recycling approaches within the aerosol industry. (MaKay, 2022)

For the aerosol valve sector, these developments hold particular significance, as they may enable the increased availability of high-quality post-consumer recycled (PCR) aluminium, thereby supporting the transition towards low-carbon manufacturing and facilitating the production of mounting cups made entirely from recycled material.

At present, only two aluminium alloys—EN AW-5052 and EN AW-5754, both typically finished with a lacquer or foil coating, are homologated for use in mounting cup production. The global supplier base capable of providing this processed, industry-approved aluminium is extremely limited, with only a small number of manufacturers certified to supply material that meets the technical and regulatory requirements of the aerosol industry.

- ADITYA BIRLA Novelis
- ALUDIUM
- ARCONIC
- LAMINAZIONE SOTTILE
- LIDAO

Leading suppliers of standard aluminium for aerosol mounting cups can guarantee the following recycling content and emission rate: (Thunemann Mark, 2023)

Table 3: Total emissions (tons CO2)

Aludium	EN-AW-5754 Alicante	5,94
Aludium	EN-AW-5754 AlicanteHRC	4,0
Novelis	AA5754	6,9
Novelis:	AA5754HRC	5,7
Laminazione:	No information	

Source: created by the author according to Aludium, Novelis and Laminazione

Table 4: Recycled Content

Novelis	HRC-5754	80-85%
Novelis:	5754 standard	46-51
Laminazione:	5754 standard	47 %

Source: created by the author according to Novelis and Laminazione

The largest share of emission reductions can be achieved through increased recycling content, whether derived from post-consumer or pre-consumer aluminium sources. Approximately 90% of total emissions are classified as Scope 3, originating from indirect sources, such as the procurement of raw materials for rolling slabs or primary aluminium for casting. By substituting a significant portion of primary material with recycled scrap, it is possible to reduce the overall carbon footprint to approximately 4.0 tonnes of CO_2 per tonne of aluminium produced. (Aludium Meeting in Alicante)

2.2.3. Availability of primary aluminium with a lower CO2 footprint

Global aluminium production increased by 3.15% between 2023 and 2024, rising from 70.781 million tonnes to 73.009 million tonnes. Aluminium smelting remains the most significant single contributor to CO_2 emissions per tonne of aluminium produced. Approximately 59% of total emissions associated with the production of primary aluminium—from bauxite mining to the cast house stage—originate from electricity generation. A transition towards hydropower and other renewable energy sources, therefore, represents a key opportunity to reduce the industry's overall carbon footprint. (International Aluminium Org., no date)

The carbon footprint of aluminium production varies considerably depending on the country of smelting and the energy mix used in the process. Globally, coal remains the dominant source of electricity for aluminium smelting, accounting for approximately 61% of total energy consumption, followed by hydropower (27%) and natural gas (10%). Regional differences are pronounced: China relies on coal for around 81% of its aluminium production, Europe generates approximately 44% from hydropower, and the Gulf Cooperation Council (GCC) countries depend on natural gas-fired power plants for about 87% of their energy supply.

Improving energy efficiency in aluminium smelting remains essential for reducing CO_2 emissions, as the carbon intensity of production is closely linked to the electricity source. Hydropower and natural gas result in significantly lower emission levels compared with coal-based systems. While expanding the use of renewable energy sources, such as solar and wind, presents a clear pathway to decarbonization, the transition away from coal-fired generation will require considerable time and investment. Consequently, primary aluminium produced in China and India typically exhibits a carbon footprint exceeding 20 tonnes of CO_2 per tonne of aluminium, whereas hydropower-based production in North America, Europe, and Russia can achieve levels below 7 tonnes of CO_2 per tonne of aluminium.

Figure 10: Power Sources for aluminium smelting

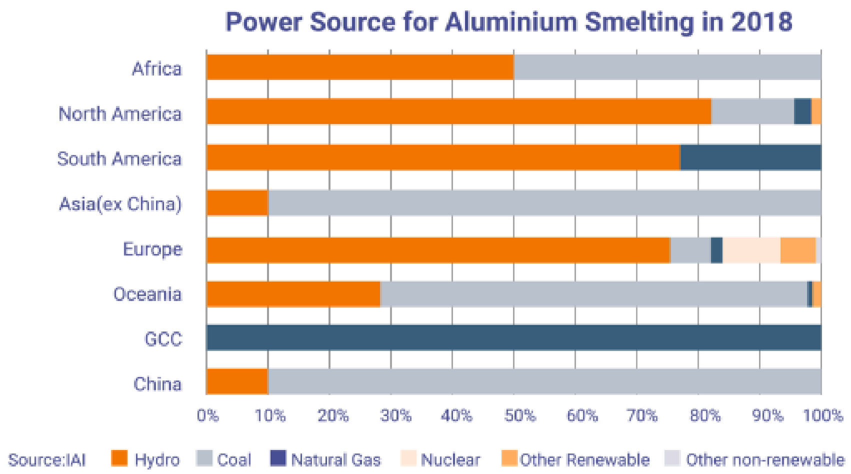


Fig. 8. Power sources for primary aluminum synthesis by electrolysis, plotted after data from the International Aluminum Institute (IAI)

Source: (Raabe et al., 2022)

The key processes generating CO2 emissions are:

- Bauxite production
- Alumina refining
- Smelting (affected by electricity fuel source)
- Ancillary materials production
- Transportation through the value chain.

The reduction of carbon intensity in aluminium production remains highly dependent on regional energy structures. In countries where coal-fired power dominates, access to renewable energy sources is often limited, making decarbonisation particularly challenging. Consequently, to achieve lower carbon footprints, it is essential to source aluminium from regions that primarily rely on hydropower or other low-emission energy sources for smelting.(de Berker, 2022)

Industrial stakeholders are increasingly seeking to source ‘low-carbon’ aluminium from smelters powered by hydropower or natural gas, as these energy sources generate significantly lower levels of CO_2 and greenhouse gas emissions compared with coal-based production. Aluminium produced through such processes typically exhibits a carbon footprint of approximately 4.0 tonnes of CO_2 per tonne of aluminium. To ensure the availability and traceability of this low-carbon material, suppliers often apply a price premium that reflects both its environmental value and the limited global supply. (de Berker, 2022)

Aludium supplies the EN AW-5754 aluminium alloy, which is certified as low-carbon, with an average footprint of approximately 4.0 tonnes of CO_2 per tonne of aluminium produced. This reduction is achieved primarily using recycled input material, incorporating a high proportion of secondary aluminium, which may include both pre-consumer and post-consumer content.

Novelis is a global leader in flat-rolled aluminium products and a key advocate of circular economy principles within the aluminium industry. The company has made substantial investments in closed loop recycling systems, enabling the recovery and reuse of post-consumer and post-industrial aluminium scrap directly into new sheet production. Novelis' low-carbon aluminium portfolio—marketed under the "Novelis Advanz" and "Novelis evercycle™" brands—achieves a carbon footprint of less than 4.0 tonnes of CO_2 per tonne of aluminium, depending on regional energy sources and scrap availability.

By integrating a high proportion of recycled content, Novelis significantly reduces energy consumption and Scope 3 emissions across its global supply chain. This approach supports the company's commitment to carbon neutrality by 2050 and aligns with the aerosol industry's objectives to increase the availability of high-quality, low-carbon aluminium alloys suitable for mounting cup and valve production.

2.2.4. Using an alternative alloy (EN AW-3104)

The recycled content of aluminium alloys largely depends on the availability and quality of scrap material. The alloy EN AW-5754 is highly suitable for recycling and can effectively incorporate scrap from the 3xxx and 5xxx alloy series. The proportion of recycled content varies according to casting parameters, but in general, a scrap input of more than 60% can be achieved, with typical ranges between 60% and 70%, depending on the quality of the recycled feedstock.

In contrast, EN AW-3104, which is the standard alloy used for beverage can bodies, benefits from access to a well-established pool of can scrap. As a result, recycling rates exceeding 80% are common, and in some cases, values of up to 95% can be achieved, depending on scrap quality and casting conditions.

Given its high recycling potential and widespread availability of scrap, EN AW-3104 presents a promising alternative for cup production. Utilising this alloy could significantly increase post-consumer recycled (PCR) content in aerosol components, thereby reducing the overall carbon footprint and advancing the industry's circular economy objectives.

Recycling content:

- >95 % for alloy EN AW-EN AW-3104 (pre- and post-consumer)
- 47 % for alloy EN AW-EN AW-5754 (pre- and post-consumer)

EN AW-3104 is widely available as post-consumer recycled aluminium because it is the dominant alloy used in beverage can production, one of the world's most recycled consumer products. The beverage can industry operates a mature, high-volume closed-loop recycling system ("can-to-can"), generating large quantities of clean, homogeneous 3104 scrap. This enables rolling mills such as Novelis to consistently offer 3104 sheets with 40–90% PCR content. In contrast, EN AW-5754 lacks such a recycling loop, resulting in minimal PCR availability.

The beverage can industry operates closed-loop recycling, meaning: A used can → collected → sorted → remelted → rolled → becomes a new can. Aluminium recyclers and rolling mills (e.g., Novelis, Constellium, Hydro) use can scrap directly to produce: new sheet alloy EN AW-3104 with very high PCR content (40–90%). Novelis is particularly known for: 75% recycled content can sheet on average, >90% PCR for some lines

2.3. Conclusion

The findings of this research confirm that 100% post-consumer recycled (PCR) aluminium is not currently available for use in packaging applications. Consequently, progress towards greater sustainability must focus on the use of alloys that minimise primary aluminium consumption. The availability of post-consumer scrap for EN AW-5754, remains extremely limited. As a result, this alloy continues to rely heavily on primary aluminium, typically exceeding 50%.

One viable strategy to reduce associated carbon emissions is the increased use of renewable energy—particularly hydropower or other low-carbon sources—in the production of primary aluminium. This approach provides an additional pathway to reduce the overall CO_2 intensity of alloy EN AW-5754.

An alternative solution involves using more commonly available aluminium grades with higher scrap content, including both post-consumer (PCR) and post-industrial (PIR) sources. The EN AW-3104 alloy, widely used in the beverage can industry, demonstrates similar mechanical properties to EN AW-5754 and therefore represents a potential substitute for mounting cup manufacturing. Typically, the primary aluminium content in EN AW-3104 ranges from 5% to 20%, while post-consumer scrap content is significantly higher due to its well-established closed-loop recycling system.

However, several technical challenges must be addressed before EN AW-3104 can be successfully implemented in aerosol valve components. These include stamping processing characteristics, such as hardness, elongation, tip height, and positioning accuracy. Additionally, the valve head's stability under internal aerosol pressure remains insufficient compared with current EN AW-5754 standards. Surface appearance variations, particularly when using transparent epoxy lacquers, also require consideration. Consequently, the transition to EN AW-3104 would require comprehensive process modifications and the development of a controlled implementation framework to ensure performance consistency and compliance with industry requirements.

CHAPTER III:

METHODOLOGY

3.1. Research Design and Methods

The methodological framework of this research combines quantitative and qualitative approaches to ensure a comprehensive analysis of the environmental implications of aluminium sourcing for mounting cup production. The study primarily relies on secondary data, including industry reports, environmental product declarations (EPDs), life-cycle assessment (LCA) data, and academic literature on aluminium production, recycling, and carbon footprint analysis. Comparative assessments are conducted between primary aluminium produced with renewable energy sources and secondary aluminium with high PCR content. Additionally, industry case studies and benchmarking analyses are used to identify practical applications, supply chain constraints, and potential technological adaptations within the aerosol packaging sector. This chapter outlines the research roadmap, detailing the approach and methods employed to address the research questions and achieve the stated objectives.

The study is based on a causal research design, which seeks to examine the cause-and-effect relationship inherent in the central research question:

"How does reducing CO_2 emissions from aluminium used in the production of mounting cups benefit the environment?"

This approach aligns with an explanatory research objective, as defined by Saunders et al. (2019).

Data Evaluation and Analytical Method:

The collected data will be subjected to comparative and interpretive analysis to assess the carbon footprint differentials between various aluminium sources and production routes. Life Cycle Assessment (LCA) principles are applied to evaluate the environmental performance of primary and secondary aluminium, with a particular focus on Scope 1, 2, and 3 emissions. Quantitative data are normalised and compared using emission factors expressed in tonnes of CO_2 per tonne of aluminium to ensure methodological consistency. Qualitative insights from industry publications and case studies complement these findings, providing contextual understanding of technological feasibility, supply chain challenges, and market implications. Together, these analytical methods enable a robust evaluation of the potential to reduce CO_2 emissions by increasing the use of low-carbon and PCR aluminium in mounting cup production.

The following specific research objectives guide the investigation by identifying and analysing the environmental effects of targeted actions:

To determine how the environment benefits from the use of primary aluminium sourced from suppliers with a low carbon footprint.

To assess the environmental advantages of using secondary aluminium (100% post-consumer recycled content) in mounting cup production.

To evaluate whether recycled aluminium (EN AW-5754 standard grade) is available in sufficient quantity and appropriate quality to support a high proportion of secondary aluminium use.

If EN AW-5754 is not available in post-consumer recycled (PCR) form, an alternative alloy, EN AW-3104, may be evaluated. This grade is commonly used in the beverage can industry and is therefore readily available as PCR material (Saunders et al., 2019).

In this study, the carbon footprint serves as the dependent variable, influenced by the independent variable—the percentage of PCR aluminium used in the production of mounting cups. The research is founded on an empirical hypothesis, supported by quantitative data, including carbon footprint assessments of aluminium production and the environmental benefits of increasing PCR aluminium utilisation. In addition, preliminary analysis is conducted using historical data to strengthen the empirical basis of the study.

The chosen research methods aim to address the central question:

"Does reducing the carbon footprint of aluminium used in mounting cup production—through the use of low-carbon primary aluminium or 100% post-consumer recycled aluminium—benefit the environment?"

If reductions in carbon intensity are achieved through either approach—by adopting greener primary aluminium or by increasing the proportion of PCR material—then measurable environmental benefits will result. Relevant data will be collected to test and support the hypothesis. Using an empirical research approach and the deductive method, this study aims to establish or refute the logical relationship between the theory that “green aluminium reduces the carbon footprint” and the underlying research question (Saunders et al., 2019).

The applied research method aims to generate specific insights and new knowledge by addressing the question of whether the use of aluminium alloy EN AW-3104 could enable a greater incorporation of post-consumer recycled (PCR) aluminium in mounting cup production.

The aerosol industry frequently promotes its products as “recycling-friendly”, given that over 50% of aerosol cans are manufactured from aluminium. Comparisons with the beverage industry often support this perception, which is widely recognised for its established and efficient recycling systems.

However, unlike beverage cans, aerosol cans currently lack a closed-loop recycling process. There is no dedicated system to collect, separate, and reintegrate the individual components—particularly the mounting cup, which is produced from aluminium alloy EN AW-5754—back into the aluminium production cycle. As a result, there is presently no mechanism for generating PCR aluminium suitable for the reproduction of mounting cups. This research, therefore, focuses specifically on mounting cups, an integral component of the aerosol valve, which is fitted to the aerosol can and plays a critical role in the overall sustainability of aerosol packaging.

To test the hypothesis, several key areas of research must be addressed.

The first stage involves examining the use of first-class primary aluminium, as its carbon footprint varies significantly depending on its energy source. This step aims to assess the environmental benefits of sourcing low-carbon or renewable-energy-based primary aluminium for mounting cup production.

The second stage focuses on evaluating the availability of post-consumer recycled (PCR) aluminium, specifically grade EN AW-5754. This includes investigating sorting processes for aerosol cans, identifying existing recycling systems, and determining potential supply sources for high-quality PCR aluminium.

The third stage concerns the modification and testing of aluminium grade EN AW-3104, which is widely used in the beverage can industry. It is proposed that one of the leading aluminium producers manufacture a modified version of EN AW-3104 suitable for mounting cups. A critical requirement is that the material must withstand internal pressures of up to 50 bar within aerosol cans. While theoretical assessments suggest that EN AW-3104 could meet these criteria, practical testing has not yet been conducted.

The successful implementation of EN AW-3104 could represent a transformative development for the global aerosol industry, enabling the use of a standardised alloy with high PCR availability. Furthermore, this study could serve as a benchmark for other sectors, such as the pharmaceutical (ferrules) and cosmetic (closures and caps) industries, which also rely on specialised aluminium grades with limited access to PCR material.

In summary, this research follows a structured, three-stage approach to evaluate the potential for reducing the carbon footprint of aluminium used in mounting cup production.

The study first analyses the environmental performance of low-carbon primary aluminium, then examines the availability and recovery pathways of PCR aluminium (EN AW-5754) and finally explores the feasibility of adopting EN AW-3104 as an alternative alloy. Collectively, these stages form a systematic research roadmap to generate empirical evidence and practical insights to advance sustainable material sourcing and circular economy practices within the aerosol valve industry.

In summary, these research objectives establish a clear framework for analysing the environmental impact of aluminium used in the production of mounting cups. The study employs a combination of literature analysis, industry data evaluation, and comparative assessment of primary and secondary aluminium sources. This methodological approach enables the identification of key factors influencing CO_2 reduction, while also assessing the availability, quality, and suitability of recycled alloys. Ultimately, the research aims to provide evidence-based insights to support sustainable material sourcing and low-carbon innovation within the aerosol valve industry.

3.2. Primary / Secondary Aluminium

The aluminium industry operates through a two-stage production process. In the primary production stage, alumina (aluminium oxide) is first extracted from bauxite ore and then converted into pure aluminium metal through electrolysis. In the secondary production stage, aluminium is refined or remelted from scrap, thereby reintroducing recycled material into the production cycle. Subsequent processing steps include casting, rolling, and extrusion, which shape the metal into its final industrial forms.

The primary smelting process—the Hall–Héroult process—was independently discovered in 1886 by Charles Martin Hall in the United States and Paul Héroult in France. It remains the dominant industrial method for producing primary aluminium from alumina, owing to its efficiency and metallurgical reliability. (Fundamentals of Aluminium Metallurgy, 2011)

Secondary aluminium production comprises two main operational stages: scrap pretreatment and smelting or refining. The pretreatment stage involves the sorting, processing, and cleaning of aluminium scrap to ensure material purity and consistency. The subsequent smelting and refining stage involve melting, purification, alloying, and casting the recovered aluminium. Through these processes, scrap aluminium is transformed into high-quality secondary metal, suitable for reuse in a wide range of industrial applications (Linhardt, 2022)

The terms “primary” and “secondary country of smelt” are critical for conducting a comprehensive life-cycle assessment (LCA) and ensuring supply chain traceability in the aluminium industry. The primary smelting country refers to the nation where bauxite is processed into alumina and subsequently converted into primary aluminium through electrolysis using the Hall–Héroult process. (GDA - Gesamtverband der Aluminiumindustrie e.V., 2020)

The secondary smelting country refers to the nation where scrap aluminium is remelted during secondary aluminium production. For example, if post-consumer scrap is collected and remelted in Germany, the secondary smelt country is identified as Germany.

Accordingly, the primary smelt country denotes the origin of virgin aluminium production, while the secondary smelt country represents the origin of recycled aluminium production. The carbon footprint differs substantially between the two processes: primary aluminium production emits approximately 12–20 tonnes of CO_2 per tonne of aluminium, depending on the energy mix (e.g., coal versus hydropower), whereas secondary aluminium production generates roughly 0.5 tonnes of CO_2 per tonne of aluminium, primarily from the remelting process. (International Aluminium Org., 2019)

Therefore, Life Cycle Assessments (LCAs), Environmental Product Declarations (EPDs), and corporate sustainability databases must clearly document both the country of production and the process type (i.e., primary or secondary smelting) to ensure the accurate calculation and comparability of emission data.

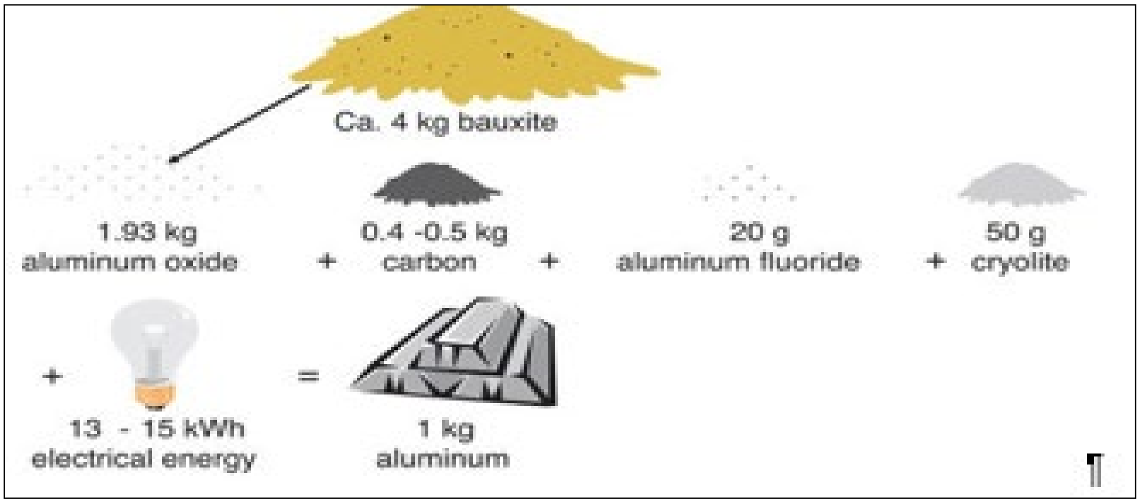
This distinction is particularly important within the global aluminium supply chain, as regional differences in energy sources, such as the reliance on coal, natural gas, or hydropower, have a significant impact on the overall carbon intensity of aluminium production. Accurately capturing these variables is therefore essential for transparent reporting, robust carbon accounting, and informed decision-making in sustainable material sourcing. (European Aluminium, 2018)

Approximately four tonnes of bauxite are required to produce two tonnes of alumina, which in turn yield one tonne of aluminium (see Figure 1). The average industry emissions associated with primary aluminium production are estimated at 9.73 tonnes of

CO_2 per tonne of aluminium, with around 55% of these emissions resulting from electricity generation—a figure that varies significantly depending on the energy source utilised.

Historically, more than half of the electricity used in aluminium production has been derived from hydropower, a trend expected to continue in the coming years. However, new smelting capacity, particularly in the Middle East, increasingly relies on natural gas-based power generation. Overall, aluminium production accounts for approximately 3% of global electricity consumption and nearly 10% of the world's hydropower usage. (Fundamentals of Aluminium Metallurgy, 2011)

Figure 11: The Aluminium Smelting Process



Source: (Kvande and Drabløs, 2014)

Recycling aluminium requires approximately 95% less energy than producing primary aluminium. In comparison, the production of post-consumer recycled (PCR) aluminium emits only 0.5 kilograms of CO_2 per kilogram of aluminium produced. On a per-tonne basis, consumer scrap (PCR) generates approximately 0.5–0.6 tonnes of CO_2 per tonne of recycled aluminium, while internal or pre-consumer scrap (PIR) results in around 0.3 tonnes of CO_2 per tonne.

According to existing literature, aluminium is theoretically 100% recyclable without any loss of mechanical or chemical properties, retaining the same characteristics as virgin material after reprocessing. However, it remains uncertain whether this assumption applies equally to aluminium used in mounting cups, given their specific alloy composition and multi-material integration within the aerosol valve system.

The environmental and economic benefits of aluminium recycling are evident but rely on effective collection, sorting, and alloy-specific recycling systems. Because mounting cups are permanently attached to aerosol cans, their separation after use presents a significant challenge. Achieving 100% recycled aluminium would only be feasible if scrap were sorted precisely by alloy type, raising concerns regarding the availability, purity, and traceability of suitable scrap streams.

Moreover, the establishment of a closed-loop recycling process depends heavily on consumer awareness and proper disposal behaviour, ensuring that used aluminium packaging is correctly sorted and recycled. This leads to a critical question: Are there any market initiatives currently utilising post-consumer recycled aluminium? At first glance, the claim of using 100% PCR aluminium appears highly promising, yet it warrants careful investigation to determine whether it reflects actual practice or remains a theoretical aspiration.

Consequently, a clear research gap exists regarding the practical availability, quality, and verification of PCR aluminium—particularly in EN AW-5754. This study aims to address this gap by examining the realistic potential for incorporating PCR aluminium into the aerosol valve industry and evaluating its actual environmental benefits.(International Aluminium Organisation, 2009)

3.3. Sources of Data Collection and Data Management

Further research is required on the use of post-consumer recycled (PCR) aluminium in the production of mounting cups for aerosol valves, as existing studies remain limited and fragmented. An exploratory research approach is therefore adopted to address this knowledge gap and to identify emerging patterns within the available data.

The first source of data collection will consist of press releases, trade publications, and technical articles published in aerosol industry journals, alongside research conducted by aluminium producers, aerosol valve manufacturers, and their industrial end users. The second source comprises existing datasets and previously published research, particularly those focusing on CO_2 emission rates and the carbon footprint associated with aluminium production.

The collected data will be managed through a structured and transparent process to ensure accuracy, consistency, and reliability. All secondary data sources—including industry reports, environmental databases, and scientific publications—will be organised, categorised, and cross-referenced by origin, publication date, and methodological relevance. Each dataset will undergo validation and plausibility checks to confirm data integrity and comparability across sources.

Proper referencing and documentation will be maintained throughout to ensure traceability and adherence to research ethics standards. Only credible and verifiable information from recognised industry bodies, peer-reviewed journals, and established sustainability databases will be used. This systematic approach supports robust data analysis and enhances the credibility of the findings.(Kvande and Drabløs, 2014)

Emissions associated with primary aluminium sourcing are derived from CRU emission factors for aluminium smelting and from International Aluminium Institute (IAI) emission factors for bauxite mining and alumina refining. Carbon footprints are initially calculated in accordance with ISO 14067, establishing a physical baseline for each aluminium alloy under study. Subsequently, customer-level carbon footprints are determined using a mass-balance chain-of-custody approach compliant with ISO 22095. Within this framework, the allocation of scrap from closed-loop recycling systems and low-carbon primary aluminium is defined and traced.

The overall CO_2 footprint of aluminium production can be reduced through two primary strategies: by increasing the share of low-carbon, first-class primary aluminium, or by enhancing the use of post-consumer recycled (PCR) aluminium, provided that sufficient quantities of EN AW-5754—the standard alloy for mounting cup production—are available in PCR form..(International Aluminium Institute 2022)

The availability of post-consumer recycled (PCR) aluminium could be significantly increased if aluminium grade EN AW-3104 proves to be technically suitable for mounting cup production. Theoretical assessments indicate that this alloy possesses the necessary mechanical and forming properties for such applications; however, practical testing and validation are required to confirm its performance under actual manufacturing and operational conditions.

Timeframes

Within the framework of descriptive research, data will be collected and compiled from a range of sources, including press releases, aluminium producers, aerosol valve manufacturers, and their end users. The subsequent stage involves a statistical evaluation of the impact on the CO_2 footprint of using either low-carbon primary aluminium or post-consumer recycled (PCR) aluminium, followed by hypothesis testing based on the results.

- A tentative timeline has been established for the testing of an alternative aluminium grade (EN AW-3104):
- Production of sample material (EN AW-3104 aluminium): approximately 2–4 months
- Material testing during stamping processes (e.g., hardness, stretchability, and earing characteristics): approximately 3–4 months
- These stages are designed to verify both the technical feasibility and environmental advantages of using EN AW-3104 as a viable alternative to

EN AW-5754, **to increase** PCR content and reduce the overall carbon footprint in mounting cup production.

3.4. Research Design Limitations

The main limitation of this research design lies in the difficulty of obtaining and verifying accurate statistical data to assess the CO_2 footprint of primary and secondary aluminium production. Although comprehensive information is available on primary aluminium manufacturing, there is a significant shortage of reliable, comparable data on secondary aluminium production and its associated carbon emissions. This constraint presents a challenge in achieving an entirely consistent life-cycle comparison between the two production routes.

To mitigate this limitation, data from multiple credible sources—including the International Aluminium Institute (IAI), CRU Group, and Environmental Product Declarations (EPDs)—were cross-referenced and validated to ensure the accuracy and robustness of the findings. Where discrepancies existed between datasets, averaged emission factors and peer-reviewed benchmarks were applied to maintain methodological consistency and enhance the reliability of comparative analyses.

3.5. Conclusion

The selection of these three variables—low-carbon primary aluminium, post-consumer recycled (PCR) aluminium, and the alternative alloy EN AW-3104—is based on their direct relevance to the study's central research hypotheses and their potential impact on reducing CO_2 emissions in the aerosol valve industry. Each variable represents a distinct pathway towards achieving environmental optimisation in aluminium sourcing and manufacturing.

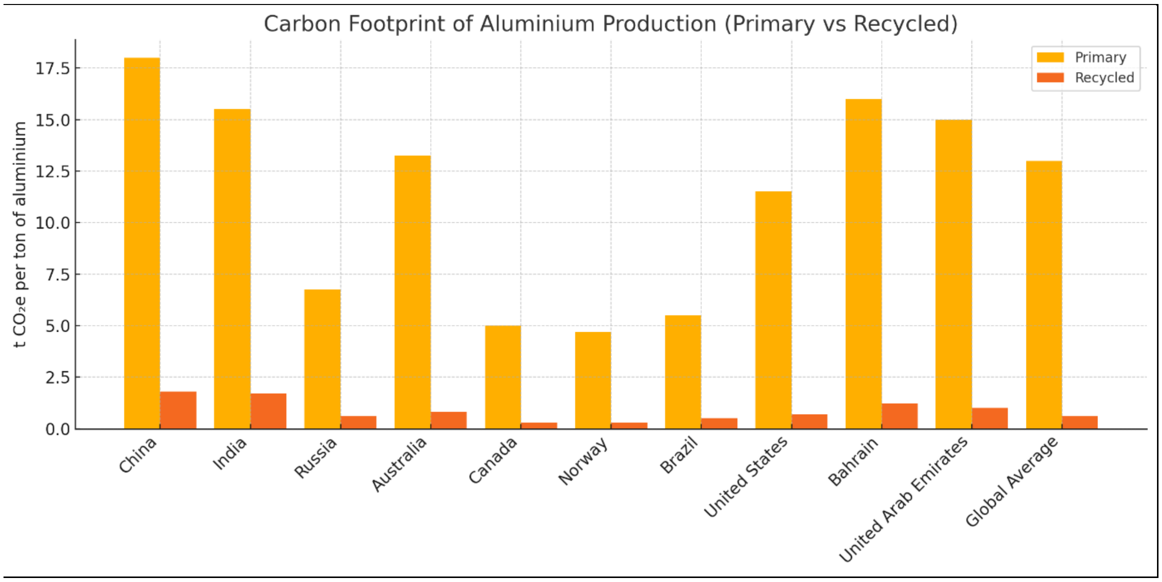
Low-carbon primary aluminium illustrates how the choice of energy source affects the production carbon footprint. PCR aluminium demonstrates the environmental advantages of circular material flows and recycling efficiency. The EN AW-3104 alloy introduces a technically viable alternative that could increase the availability of recycled content while maintaining the required mechanical performance for mounting cup production. Together, these variables form the foundation for the empirical analysis and support a comprehensive evaluation of sustainable material strategies within the aluminium supply chain.

3.5.1. Use more first-class aluminium

Primary aluminium production in China and India typically exhibits a carbon footprint of approximately 16–18 tonnes of CO_2 per tonne of aluminium, reflecting the continued reliance on coal-based electricity generation. In contrast, primary aluminium produced using hydropower, particularly in North America, Europe, and Russia, achieves a significantly lower footprint, generally below 7 tonnes of CO_2 per tonne of aluminium.

The following table provides total emissions for both primary and recycled aluminium production across all major producing countries and the global average. (International Aluminium Institute, 2023)

Figure 12: Carbon footprint of aluminium production



Source: created by the author (International Aluminium Institute, 2023)

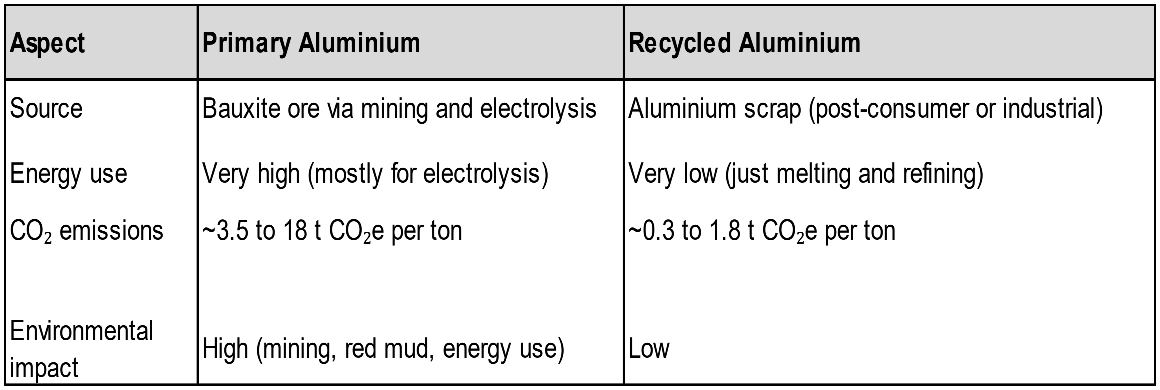
All figures presented are rounded mid-range estimates derived from recent industry publications, including the International Aluminium Institute (IAI) 2024 update, corporate sustainability reports, and peer-reviewed life cycle assessment (LCA) studies. Actual carbon footprints may vary depending on smelter technology, the composition of the electricity grid, and the system boundaries used for accounting.(International Aluminium Org., 2019)

Recycled aluminium, also referred to as secondary aluminium, is produced through the re-melting of aluminium scrap rather than by extracting metal from bauxite ore. It comprises two main categories:

Post-consumer scrap – derived from end-of-life products, such as beverage cans, vehicle components, and window frames.

Post-industrial scrap – originating from manufacturing processes, such as offcuts and production waste from aluminium sheet fabrication.

Figure 13: Primary / Recycled Aluminium Comparison



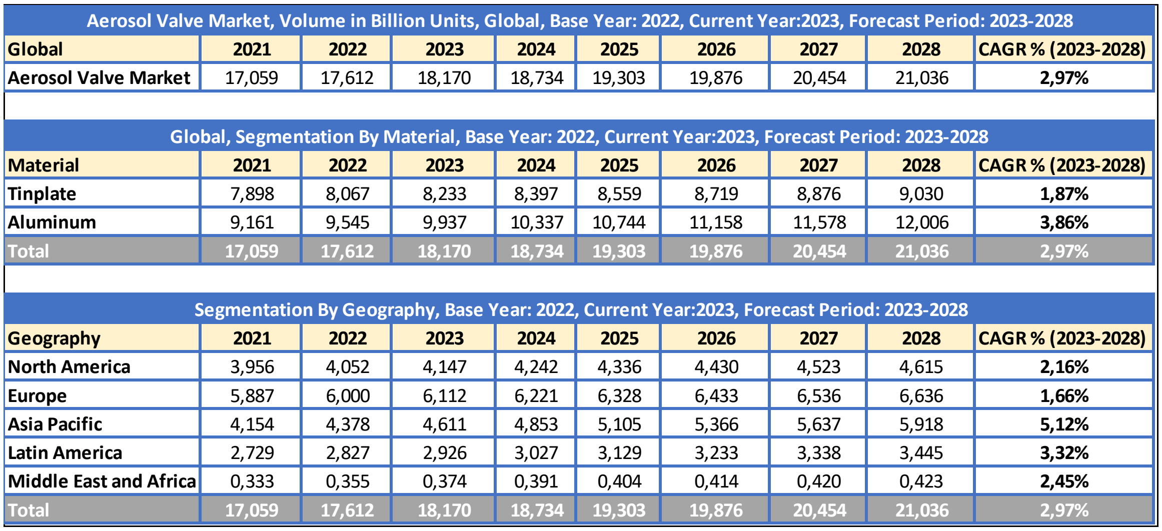
Aspect	**Primary Aluminium**	**Recycled Aluminium**
Source	Bauxite ore via mining and electrolysis	Aluminium scrap (post-consumer or industrial)
Energy use	Very high (mostly for electrolysis)	Very low (just melting and refining)
CO_2 emissions	~3.5 to 18 t CO_2e per ton	~0.3 to 1.8 t CO_2e per ton
Environmental impact	High (mining, red mud, energy use)	Low

Source: created by the author.

In 2022, global aerosol production reached approximately 15.4 billion units. Europe accounted for the largest share, producing around 5.319 billion cans, with notable contributions from the United Kingdom, Germany, and France. The market is expected to continue expanding, with forecasts projecting total production to reach approximately 19.8 billion units by 2026. (Mordor Intelligence, 2023b)

In practical terms, reducing dependence on primary aluminium allows a substantial portion of Scope 3 emissions to be substituted with a comparatively smaller share of Scope 1 emissions. This shift enhances the overall carbon efficiency of the production process by significantly reducing emissions from transportation and upstream raw material extraction. Moreover, it improves supply chain transparency and supports the integration of circular economy principles, enabling companies to demonstrate measurable progress toward their decarbonisation targets.

Table 5: Global Aerosol Valve Market



Aerosol Valve Market, Volume in Billion Units, Global, Base Year: 2022, Current Year:2023, Forecast Period: 2023-2028

Global	2021	2022	2023	2024	2025	2026	2027	2028	CAGR % (2023-2028)
Aerosol Valve Market	17,059	17,612	18,170	18,734	19,303	19,876	20,454	21,036	**2,97%**

Global, Segmentation By Material, Base Year: 2022, Current Year:2023, Forecast Period: 2023-2028

Material	2021	2022	2023	2024	2025	2026	2027	2028	CAGR % (2023-2028)
Tinplate	7,898	8,067	8,233	8,397	8,559	8,719	8,876	9,030	**1,87%**
Aluminum	9,161	9,545	9,937	10,337	10,744	11,158	11,578	12,006	**3,86%**
Total	17,059	17,612	18,170	18,734	19,303	19,876	20,454	21,036	2,97%

Segmentation By Geography, Base Year: 2022, Current Year:2023, Forecast Period: 2023-2028

Geography	2021	2022	2023	2024	2025	2026	2027	2028	CAGR % (2023-2028)
North America	3,956	4,052	4,147	4,242	4,336	4,430	4,523	4,615	**2,16%**
Europe	5,887	6,000	6,112	6,221	6,328	6,433	6,536	6,636	**1,66%**
Asia Pacific	4,154	4,378	4,611	4,853	5,105	5,366	5,637	5,918	**5,12%**
Latin America	2,729	2,827	2,926	3,027	3,129	3,233	3,338	3,445	**3,32%**
Middle East and Africa	0,333	0,355	0,374	0,391	0,404	0,414	0,420	0,423	**2,45%**
Total	17,059	17,612	18,170	18,734	19,303	19,876	20,454	21,036	2,97%

Source: (Mordor Intelligence 2023)

3.5.2. Use more PCR aluminium

Aluminium scrap is divided into two main categories: post-consumer and pre-consumer scrap.

PCR: Post-Consumer Recycled Material

Post-consumer recycled (PCR) material refers to resources recovered from products that have reached the end of their useful life. Unlike post-industrial recycled (PIR) material, which originates from industrial production waste, PCR material is sourced from end-user waste that has been collected, sorted, and reprocessed. The recycling of PCR aluminium is often technically complex, as such material can be contaminated or mixed with other substances, making separation and purification processes more challenging. The specific requirements and definitions for PCR materials are outlined in DIN EN ISO 14021:2016.

Post-consumer recycled content refers to material derived from items that consumers recycle daily. Aluminium produced from 100% post-consumer waste is obtained entirely from recycled aluminium collected at the end of life, meaning the scrap originates directly from the consumer recycling stream rather than from manufacturing residues. (International Aluminium Organisation, 2009)

PIR: Post-Industrial Recycled Material

Post-industrial recycled (PIR) material refers to waste generated and separated during manufacturing. This material is typically sorted and collected independently of other waste streams. Because its composition and origin are well-documented, the processing and reintroduction of PIR material into the production cycle are relatively straightforward, resulting in consistently high-quality recycled products. The formal definitions and specifications for post-industrial recycled materials are provided in DIN EN ISO 14021:2016.

Scrap produced throughout a product's manufacturing process is generally recycled within the same production system, a practice that can be modelled as a closed-loop recycling process."(International Aluminium Organisation, 2009)

At the same time, this study seeks to raise awareness of the importance of aluminium recycling within the context of sustainable material sourcing. The EN AW-5754 alloy could potentially incorporate post-consumer scrap originating from aluminium profiles recovered during building demolitions, some of which may be partially coated or painted. However, this profile scrap often contains silicon impurities, which are undesirable in EN AW-5754 compositions. To counterbalance the silicon content and restore alloy purity, a "1000-series" alloy must be added during the recycling process. (Kreidel Christian, 2023)

In general, 5000-series aluminium scrap collected from household sources is typically mixed and heterogeneous, making it unsuitable for use as post-consumer recycled (PCR) material. In contrast, aluminium scrap generated within the automotive industry is fully recycled in a closed-loop system, enabling it to be reprocessed and reused without compromising alloy integrity or performance.

This distinction between open-loop and closed-loop recycling is crucial for achieving high-purity PCR aluminium. Only through controlled, closed-loop recycling streams can the chemical composition and mechanical properties of the material be preserved—an essential requirement for mounting cup production, where alloy precision and performance consistency are critical.(Kreidel Christian, 2023)

Currently, approximately 40% of aluminium production already incorporates scrap generated during hot and cold rolling processes. However, it remains challenging to provide an accurate and meaningful estimate of the overall recycled content within final products. A significant portion of metal scrap generated in Germany is exported to countries such as Malaysia for processing and subsequently shipped to China for further utilisation. This practice harms the domestic recycling industry, as German recyclers often obtain higher revenues from exporting scrap than from processing and reintroducing it into local recycling streams. (Kreidel Christian, 2023)

Recent trade and industry data indicate that large quantities of aluminium scrap generated within the European Union, including Germany, are exported rather than recycled domestically. According to figures from the World Bank (WITS), Trend Economy, and the International Aluminium Institute (IAI), the EU exports approximately 1.0–1.2 million tonnes of aluminium scrap (HS 7602) annually, valued at around US $2 billion. Most of these exports are directed to Asian countries such as Malaysia, India, Pakistan, and Turkey, which have become major processing hubs for secondary metals.

In Germany, aluminium scrap exports were valued at roughly US $2 billion in 2023, with substantial volumes also being re-exported after initial collection and sorting. While the country remains a central recycling centre within the EU, domestic recyclers often obtain higher revenues from exporting scrap abroad than from processing it locally. This economic incentive has led to a significant outflow of recyclable material, weakening Europe’s ability to sustain a closed loop recycling system and undermining the availability of high-quality post-consumer recycled (PCR) aluminium for local industries. (European Aluminium, 2025a)

Industry associations, such as European Aluminium, have raised concerns that these export patterns are tightening domestic scrap supply, thereby limiting progress towards low-carbon and circular production systems. The organisation has called for policy interventions, including potential export duties or enhanced monitoring of scrap flows, to retain valuable secondary raw materials within the European market. (European Aluminium, 2025a)

This trend highlights a critical paradox: while aluminium is theoretically infinitely recyclable, the economic structure of the international scrap trade often drives material away from regions most committed to sustainable production. The consequence is a dependence on imported or primary aluminium, which carries a substantially higher CO_2 footprint, thereby hindering efforts to decarbonise the European aluminium value chain.

Life Cycle Assessment (LCA) studies indicate that some aluminium producers combine pre-consumer and post-consumer scrap within the same recycling stream when marketing their products as “recycled aluminium.” This practice can distort environmental accounting, as it incentivises the generation of production waste and enables high-carbon primary aluminium to be reclassified as low- or zero-carbon recycled material. For example, aluminium produced using coal-based electricity retains its original carbon footprint, which cannot be erased simply by re-melting production scrap and returning it to the furnace. (International Aluminium Org., 2019)

This challenge highlights the need for stronger traceability frameworks and the adoption of robust chain-of-custody standards, such as ISO 22095, to ensure that recycled content claims accurately reflect genuine post-consumer recovery and that carbon footprints are reported transparently and with methodological consistency. (International Aluminium Org., 2019)

The most effective approach for managing aluminium production scrap is to re-melt and reuse it, a well-established practice across the aluminium industry. As a permanently recyclable material, aluminium can be reprocessed indefinitely without any loss of its mechanical or chemical properties. Internal process scrap, such as offcuts or rejected parts, is typically returned directly into the same production cycle. In contrast, post-consumer scrap is collected, sorted, and remelted to produce secondary aluminium. The utilisation of scrap in production offers substantial benefits, including an approximate 95% reduction in energy consumption, a decrease in CO_2 emissions of up to 95%, and significant cost savings compared with primary aluminium production. (International Aluminium Organisation, 2009)

Does aluminium scrap still contribute to CO_2 emissions? The answer depends mainly on the defined system boundaries and allocation rules applied within the Life Cycle Assessment (LCA) framework.:

1. Internal Production Scrap (Pre-consumer)

This category of scrap already includes embedded CO_2 emissions from primary aluminium production, encompassing Scopes 1, 2, and 3. When such scrap is reused within the same production system, these emissions are not avoided, as they have already been accounted for in the original product's carbon footprint. However, if the scrap is sold or transferred to an external system, Life Cycle Assessment (LCA) standards, such as ISO 14044, recommend applying allocation procedures to distribute the associated emissions—for instance, through 50/50 partitioning or economic allocation methods—to ensure fair and transparent attribution of environmental burdens. (DIN ISO 14040, 1995)

2. Post-consumer Scrap (PCR – Post-Consumer Recycled)

This stage is typically where the carbon benefits of recycling are credited. Most post-consumer recycled (PCR) aluminium is classified as a "zero-burden" material, meaning it carries no residual Scope 1, 2, or 3 emissions from its previous life cycle. Only the emissions associated with re-melting and transportation—usually ranging between 0.3 and 1.8 tonnes of CO_2 per tonne of aluminium—are included in the assessment. International standards such as ISO, Environmental Product Declarations (EPDs), and the Greenhouse Gas (GHG) Protocol recognise and support this "cut-off" approach, effectively rendering PCR aluminium almost carbon-neutral from a materials accounting perspective.(European Aluminium, 2018)

Examples:

Example 1: Internal scrap (pre-consumption – reused in the same plant)

Example 1: Internal recycling within the same production system

Situation: An aluminium plate is rolled, generating approximately 10% process scrap, which is immediately remelted and reused within the same facility.

System boundary: Cradle-to-gate — confined to operations within a single plant.

Allocation: No diversion — the process remains entirely internal.

Outcome: The CO_2 burden remains unchanged, as the scrap continues to carry the full embedded carbon footprint of the original primary aluminium. Consequently, no reduction in the overall CO_2 footprint occurs.

Example 2: Sale of pre-consumer scrap to a third party

Situation: A rolling mill sells 500 tonnes of clean aluminium scrap to another company for reprocessing.

System boundary: Transition between Producer A and Recycler B.

Allocation: Economic or physical allocation must be applied to distribute the carbon burden between the two entities in accordance with LCA principles.(DIN ISO 14040, 1995)

The distribution of CO_2 emissions depends on the allocation methodology defined by prevailing LCA regulations and standards. Under economic allocation, emissions are distributed proportionally based on the market value of the respective material flows. In contrast, under system expansion, the original producer (A) is credited as though the production of primary aluminium had been avoided. Alternatively, when applying the cut-off approach, the purchaser (B) receives the material as CO_2-free input, with no upstream emissions transferred from the original production process.

Example 3: Post-consumer scrap (e.g., beverage cans)

Situation: An aluminium beverage can is collected after consumer use and subsequently recycled into a new product.

System boundary: Cradle-to-cradle — representing a complete product life cycle.

Allocation: Cut-off method — the standard approach applied in Environmental Product Declarations (EPDs) and Product Category Rules (PCRs).

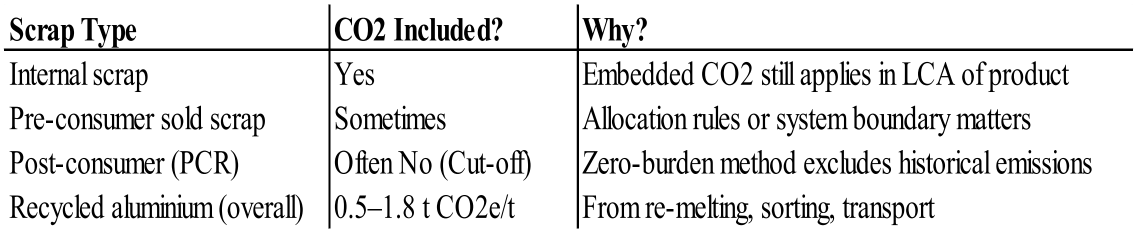
Outcome: No CO_2 emissions are carried over from the original product, as the carbon burden ends at the point of disposal. The new can, produced from recycled material, accounts for only the emissions generated during collection, sorting, transport, and remelting, typically ranging from 0.5 to 1.8 tonnes of CO_2 equivalent per tonne of aluminium. (International Aluminium Org., 2019)

Example 4: Mixed scrap (post-industrial and post-consumer)

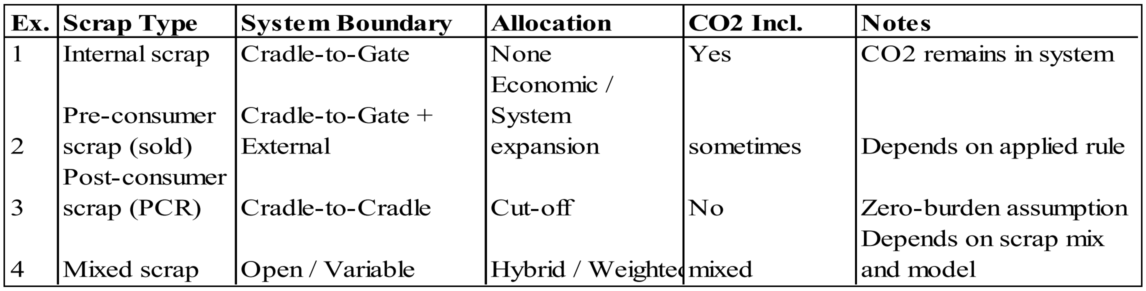
Situation: A recycling facility combines production residues (post-industrial scrap) with end-of-life materials (post-consumer scrap) during reprocessing. System boundary: Not clearly defined — the boundary conditions vary depending on the proportion and origin of each scrap type. Allocation: Hybrid allocation methods are required.

Outcome: Complex modelling becomes necessary, as Life Cycle Assessments (LCAs) must distinguish between “burden-free” materials (PCR scrap) and “burdened” materials (production waste). This differentiation is often achieved through weighted averaging, mass-balance calculations, or other hybrid allocation techniques to ensure accurate emission attribution.

Figure 14: Treatment of aluminium scrap in CO_2 accounting



Scrap Type	CO2 Included?	Why?
Internal scrap	Yes	Embedded CO2 still applies in LCA of product
Pre-consumer sold scrap	Sometimes	Allocation rules or system boundary matters
Post-consumer (PCR)	Often No (Cut-off)	Zero-burden method excludes historical emissions
Recycled aluminium (overall)	0.5–1.8 t CO2e/t	From re-melting, sorting, transport



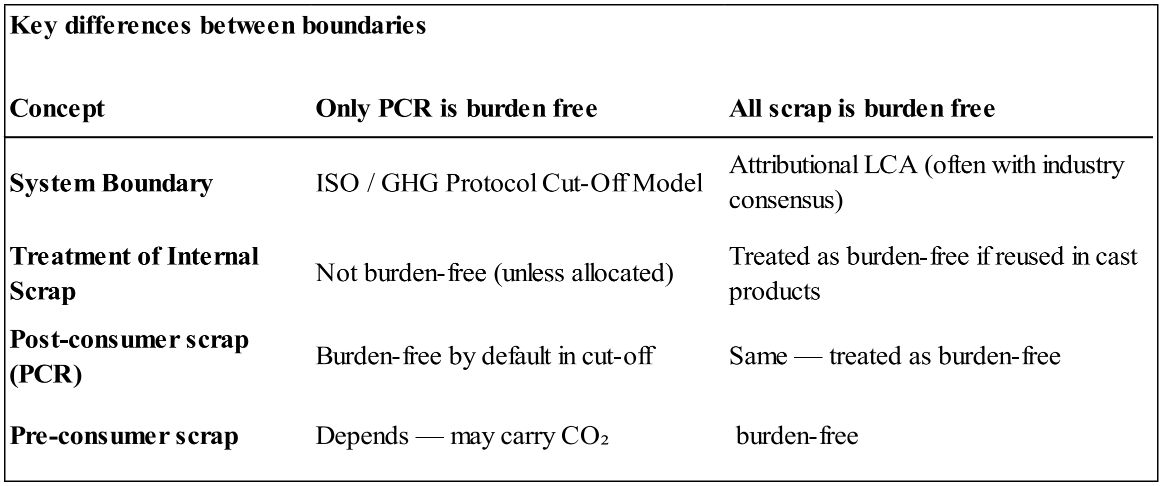
Ex.	Scrap Type	System Boundary	Allocation	CO2 Incl.	Notes
1	Internal scrap	Cradle-to-Gate	None	Yes	CO2 remains in system
2	Pre-consumer scrap (sold)	Cradle-to-Gate + External	Economic / System expansion	sometimes	Depends on applied rule
3	Post-consumer scrap (PCR)	Cradle-to-Cradle	Cut-off	No	Zero-burden assumption
4	Mixed scrap	Open / Variable	Hybrid / Weighte	mixed	Depends on scrap mix and model

Source: created by the author based on IAI 2022 Aluminium Association 2021

Under the cut-off method, the concept of zero burden implies that no CO_2 emissions from a material's previous life cycle are carried over or attributed to the recycled product. For instance, when an aluminium beverage can is recycled as post-consumer scrap, the emissions associated with its original production—including bauxite mining and primary aluminium smelting—are excluded from the new product's carbon balance. Only the processes directly involved in recycling, such as collection, sorting, transport, and re-melting, are accounted for, typically resulting in 0.5 to 1.8 tonnes of CO_2 per tonne of recycled aluminium.(International Aluminium Institute, 2023)

The treatment of scrap emissions depends on the Life Cycle Assessment (LCA) system boundaries and the accounting methodology applied. In many cases, the following principle holds: "All scrap used in the production of cast aluminium products is considered burden-free with respect to CO_2 emissions." This assumption is applied to both internal (process) scrap and external scrap, including mixtures of pre-consumer and post-consumer materials, which are collectively treated as having no inherited carbon burden within the LCA framework. (European Aluminium, 2018)

Figure 15: Key differences between boundaries



Key differences between boundaries

Concept	**Only PCR is burden free**	**All scrap is burden free**
System Boundary	ISO / GHG Protocol Cut-Off Model	Attributional LCA (often with industry consensus)
Treatment of Internal Scrap	Not burden-free (unless allocated)	Treated as burden-free if reused in cast products
Post-consumer scrap (PCR)	Burden-free by default in cut-off	Same — treated as burden-free
Pre-consumer scrap	Depends — may carry CO_2	burden-free

Source: created by the author based on IAI 2022; Aluminum Association 2021, ISO 14044, Frischkneht

Why does this create a contradiction?

The "burden-free for all scraps" approach is widely applied in the industry, as seen in Environmental Product Declarations (EPDs) for casting, extrusion, and flat-rolled aluminium products. This method is based on two key assumptions:

- All internal and external scrap is reused within closed-loop systems, and
- Recovered aluminium effectively substitutes primary aluminium, thereby being credited with zero CO_2 emissions.

This approach is particularly prevalent when pre-consumer and post-consumer scrap streams are combined, making it impractical to assign or trace individual carbon burdens. It aligns with the "cut-off plus recycled content" methodology defined in:

EN 15804+A2,

Product Category Rules (PCRs) for the aluminium sector, and

Industry Life Cycle Assessments (LCAs) conducted across Europe and North America.

However, a methodological contradiction arises because international standards such as ISO 14044 and the GHG Protocol specify that only post-consumer (PCR) scrap should be treated as burden-free under the strict cut-off approach, unless otherwise justified. In contrast, internal and pre-consumer (PIR) scrap often retains its original carbon burden in academic research and regulatory assessments, to ensure a more accurate attribution of emissions within the material's life cycle. (GHG Greenhouse Gas Protocol, 2025)

Figure 16: Treatment of aluminium scrap in CO_2 accounting

Scrap Type	**GHG Protocol / ISO Default**	**EPDs / Industry LCAs (e.g. for castings)**
Internal scrap	CO_2 included	Often treated as burden-free
Pre-consumer scrap	Allocation or partial CO_2	Often burden-free if mixed with PCR
Post-consumer scrap	Zero-burden (cut-off)	Zero-burden

Source: created by the author based on ISO 14044, GHG Protocol and Life cycle assessment

The statement that “only PCR is burden-free” represents an industry-specific convention, particularly within the context of cast aluminium production. In contrast, the broader assertion that “all scrap is burden-free” reflects a generalised interpretation within Life Cycle Assessment (LCA) practice and is aligned with strict ISO and GHG Protocol principles. Both perspectives are methodologically valid, yet they stem from different interpretative approaches to emission allocation.

The latter interpretation, based on the ISO 14044 framework, is more stringent, as it does not automatically exempt internal or pre-consumer scrap from its inherited carbon burden, thereby avoiding the application of a blanket “burden-free” assumption across all scrap categories.

Figure 17: Treatment of different aluminium scrap categories across sectors and standards

Sector	**Internal Scrap**	**Pre-consumer Scrap**	**Post-consumer Scrap (PCR)**
Casting	burden-free	burden free (if mixed)	Zero-burden
Extrusion	burden-free	burden-free	Zero-burden
Rolling (Packaging)	*burden-free*	*burden-free*	*Zero-burden*
ISO 14044	burdened	depends	Zero-burden

Source: created by the author based on IAI 2022, Aluminum Association 2022; ISO 14044:2006; Frischknecht 2007

The four examples illustrate how system boundaries, allocation methods, and scrap origin determine CO_2 emissions attribution in the Life Cycle Assessment (LCA) of aluminium products.

In Example 1, internal recycling within the same facility shows that no carbon reduction occurs, as the scrap retains the complete embedded CO_2 footprint of the original primary aluminium. Example 2 illustrates that when pre-consumer scrap is sold externally, ownership transfer necessitates the use of allocation procedures—either economic or physical—to fairly distribute the carbon burden between the producer and the recycler.

Example 3, focused on post-consumer scrap (PCR), applies the cut-off method, under which the recycled material is considered “burden-free,” with emissions assigned only to recycling-related processes, such as sorting, transportation, and remelting. In contrast, Example 4 shows the complexity of mixed-scrap systems, where post-industrial and post-consumer scrap are combined. Such scenarios require hybrid allocation or mass-balance approaches to differentiate between burden-free and burdened materials.

Collectively, these examples demonstrate that the interpretation of carbon responsibility in aluminium recycling is highly dependent on LCA methodology and system definition. While industrial practice often favours simplified “burden-free” assumptions to facilitate reporting, more rigorous academic and regulatory frameworks, such as ISO 14044, demand explicit differentiation between internal, pre-consumer, and post-consumer scrap to ensure transparent and comparable carbon accounting.

The product examined in this thesis is rolled aluminium, which is subsequently lacquered or PET-coated for use within the packaging industry.

Post-Consumer Scrap

- The EN AW-5754 alloy can absorb substantial amounts of scrap and therefore requires only a limited proportion of primary aluminium in its production. Profile scrap recovered from demolition activities in the construction sector, often partially coated or painted, is commonly utilised as post-consumer scrap. However, a key challenge lies in its silicon content, as silicon is undesirable in the 5754-alloy composition. To neutralise this impurity, a 1000-series alloy is typically added during processing. Nevertheless, post-consumer scrap from the 1000 series—for example, pressure plates—is available only in small quantities, which limits its overall contribution to the recycling mix. (Kreidel Christian, 2023)
- The EN AW-3104 alloy, widely used in the beverage can industry, consists of two aluminium series: a 3000-series alloy for the can body and a 5000-series alloy for the lid. During recycling, the 5000-series fraction is typically oxidised or burned off in the furnace, a process that purifies the recovered aluminium. This refining effect enhances the material quality and consistency of the recycled metal, thereby improving its potential suitability for applications such as mounting cup production, where uniform alloy composition and mechanical stability are critical requirements.

- In general, 5000-series aluminium scrap originating from household sources is typically heterogeneous and mixed, making it unsuitable for use as post-consumer recycled (PCR) material. In contrast, 5000-series aluminium from the automotive sector is fully recycled within a closed-loop system, ensuring that the material retains its alloy integrity and quality. Overall, there is sufficient availability of 5000-series scrap to enable the production of low-carbon or "ECO" aluminium products, if material segregation and traceability are maintained adequately throughout the recycling process.(Kreidel Christian, 2023)
- The proportion of recycled material today already consists of 40% scrap that is produced during hot or cold rolling. However, assigning meaningful values to the recycled content of the product is highly challenging. Hydro, for example, only counts PCR as containing 0% emissions.
- There is no closed-loop recycling system for the EN AW-5457 alloy, as aerosol products are distributed globally, making the recovery and segregation of alloy-specific scrap impractical. In Life Cycle Assessments (LCAs), all scrap used in the production of cast aluminium products is generally treated as "burden-free" with respect to CO_2 emissions. This assumption applies to both internal (process) scrap and external scrap, where pre- and post-consumer materials are commingled and therefore cannot be differentiated within the recycling process.

This assumption is consistent with the current guidelines of the International Aluminium Institute (IAI) and European Aluminium (EA), as well as with the requirements outlined in ISO 14067 for carbon footprint (CF) calculations.

- External scrap, comprising commingled pre- and post-consumer materials, is classified as waste utilised in a different life cycle from that in which it was initially generated, thereby representing an open-loop recycling system.
- Closed-loop systems, by contrast, avoid the need for allocation rules, as the scrap is considered "burden-free" within the same product system.
- ISO 14067 also permits the avoidance of allocation in open-loop systems, provided that these systems can be demonstrated to meet the criteria of closed-loop recycling—that is, when the recycled product retains the same inherent properties (such as alloy composition, thickness, and temper) as the primary material.

According to Product Category Rules (PCR 2022:08), the environmental impacts of scrap generation—whether from pre- or post-consumer sources—are excluded from the assessment of the new life cycle in which the scrap is utilised.

The use of waste within a production line and its reintroduction into production are considered beneficial uses, not recycling.(Speira GmbH, 2025)

The end-of-waste status for aluminium scrap is defined in Council Regulation (EU) No. 333/2011 of 31 March 2011, which sets out the criteria determining when specific categories of metal scrap cease to be classified as waste, in accordance with Directive 2008/98/EC of the European Parliament and of the Council.

To achieve end-of-waste status, aluminium scrap must meet the following conditions, as stipulated in Council Regulation (EU) No. 333/2011:

- The scrap meets the required technical quality standards, ensuring it is suitable for use in specific industrial processes or applications.
- The scrap is free from hazardous substances or contamination, including oils, coatings, plastics, and other non-metallic residues, that could compromise its recyclability or pose environmental or health risks.
- The scrap has been processed or treated so that it can be directly used in the manufacture of metal products without the need for further pre-treatment.
- There is a clear and verifiable market or demand for the scrap, demonstrating that it is a valuable secondary raw material rather than a waste product.
- The scrap meets the applicable environmental and regulatory requirements, including documentation confirming that it has been collected, transported, and processed responsibly in compliance with EU waste management legislation.

When the conditions for achieving end-of-waste status are met, aluminium scrap is classified as a secondary raw material and may exit the product system boundaries accordingly. Pre-consumer scrap is treated in line with the recommendations of ISO 14044 and the alternative approach described in EN 15804, which—under definition 3.30—classifies both pre-consumer and post-consumer waste as secondary materials.

At present, the recycled content of aluminium used in mounting cup production exceeds 50%, comprising mainly of pre-consumer scrap. Increasing the proportion of recycled aluminium in this product category directly and measurably reduces associated CO_2 emissions, thereby contributing to the overall decarbonisation of the aerosol packaging value chain.

Aluminium scrap within a closed-loop system

The following figure illustrates the flow of aluminium scrap recovered and recycled within a closed-loop system, where the material is reintroduced into the same production cycle from which it originated.

Figure 18: Closed Loop System

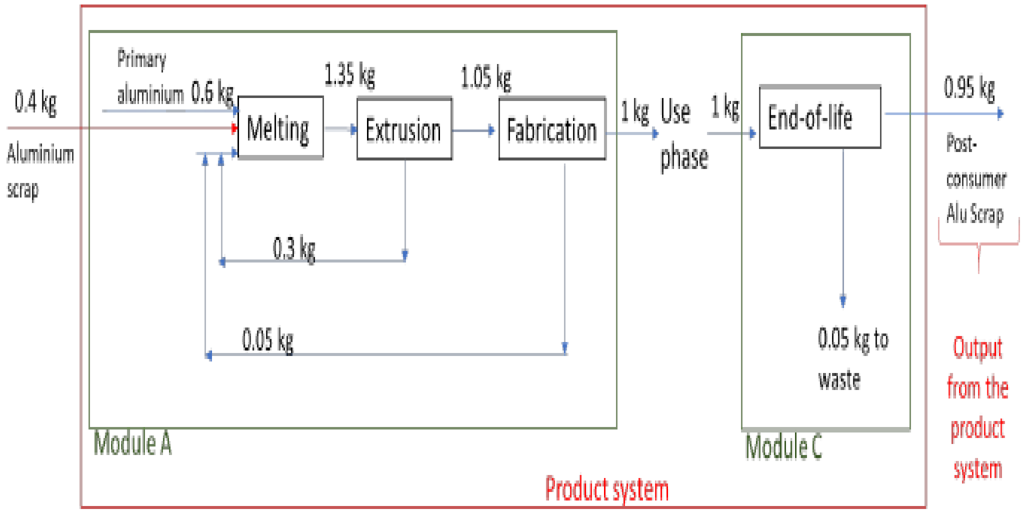


Figure 2. Example of closed loop modelling for 1 kg of aluminium profile used in the final product. Note to the Figure: in the example reported in the figure the process losses within the value chain (for example due to oxidation in the melting) are not included to facilitate the understanding. However, such losses shall always be included in real calculations.

Source: (European Aluminium, 2020)

Aluminium scrap within an open-loop system

The following figure illustrates the flow of aluminium scrap generated and recycled through an open-loop system, where the material is repurposed in a different production cycle or product application from that in which it was originally used.

Figure 19: Open Loop System

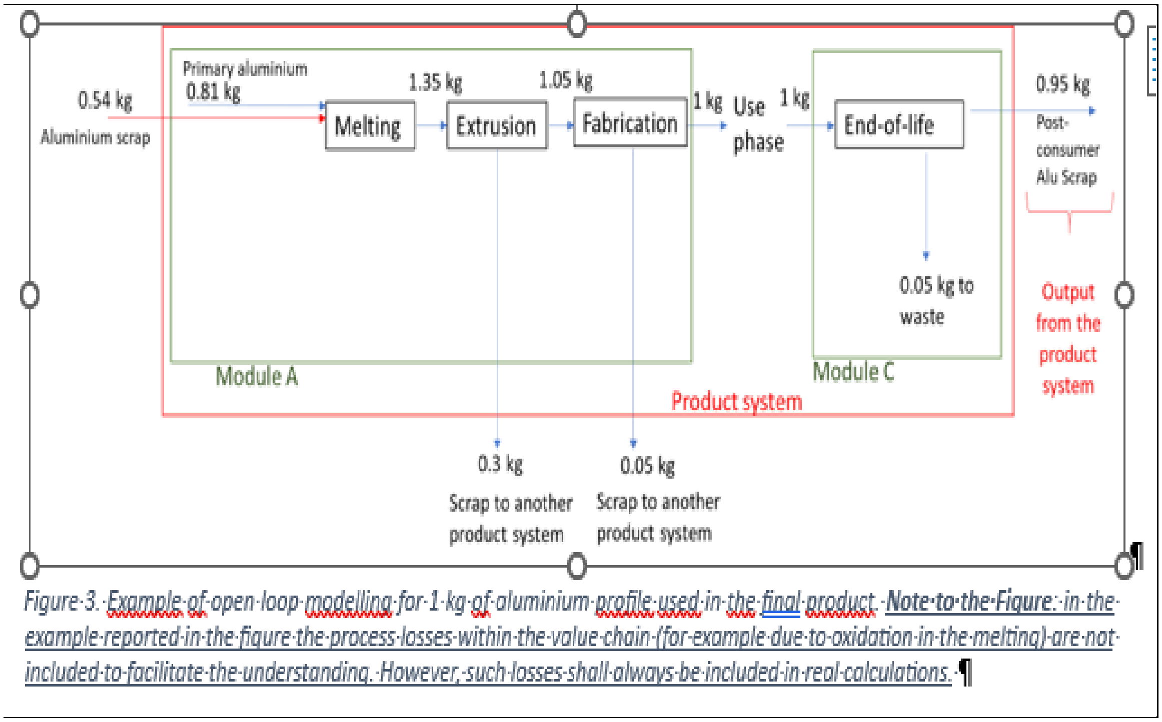


Figure 3. Example of open loop modelling for 1 kg of aluminium profile used in the final product. Note to the Figure: in the example reported in the figure the process losses within the value chain (for example due to oxidation in the melting) are not included to facilitate the understanding. However, such losses shall always be included in real calculations.

Source: (European Aluminium, 2020)

In contrast to a closed-loop system, aluminium scrap within an open-loop system exits the original product system. It is subsequently utilised in a different production process or product application.

Companies such as Novelis, Aludium, and Laminazione Sottile operate their own in-house smelting facilities, enabling them to process and recycle EN AW-5754 aluminium on-site. In such cases, the material remains within a closed-loop recycling system and can therefore be classified as “burden-free” aluminium scrap under Life Cycle Assessment (LCA) principles.

To ensure transparency and credibility, verification of burden-free status must be conducted by an independent third party that is not involved in the life-cycle assessment or the development of the corresponding environmental declaration.(Novelis, 2024)

All calculations are based on the under the Zero-Burden / Cut-Off Method, scrap enters the system with *zero upstream burdens*

3.5.3. Introduction of an Alternative Aluminium Grade: EN AW-3104

Given the limited availability of post-consumer recycled (PCR) aluminium in the standard EN AW-5754 alloy, this study explores the potential of EN AW-3104 as an alternative material for mounting cup production. EN AW-3104 is widely used in the beverage can industry, where well-established recycling systems and high PCR recovery rates are already in place.

The alloy exhibits mechanical behaviour comparable to that of EN AW-5754, including adequate formability and strength, making it a technically viable substitute. Moreover, its greater availability within the global recycling stream—derived from the large volume of aluminium beverage cans in circulation—could significantly enhance the use of recycled content in aerosol valve manufacturing.

Adopting EN AW-3104 for this application would therefore represent a strategic step towards increasing PCR utilisation, reducing dependence on primary aluminium, and lowering the overall carbon footprint of aerosol packaging components.

Table 6: Properties of Aluminium Grade EN-AW 3104 and EN-AW-5754

Specification	**Leg**	**Rp0.2(Mpa)**	**Rm(Mpa)**	**A50(%)**	**Earing**
EN-AW 5754 H42	AlMg3	175-210 (avg. 190)	230-270 (avg. 260)	>7 (avg. 9)	45°, <3%
EN-AW 3104 H 44	AlMn1Mg1Cu	>190	>210	>3	45°, <3%

Source: (Novelis, 2023)

Alloy (leg): Aluminium alloys consist predominantly of aluminium, with key alloying elements including manganese (Mn), magnesium (Mg), copper (Cu), silicon (Si), and zinc (Zn). In most cases, Al99.5—representing 99.5% pure aluminium—is used as the base material. Through alloying, the mechanical strength of aluminium can be enhanced over a wide range. At the same time, additional properties such as formability, corrosion resistance, and surface quality can also be optimised.

For mounting cup production, the standard alloy currently used is a 5000-series (Class 5) alloy, whereas the proposed alternative material, EN AW-3104, is a 3000-series (Class 3) alloy.

RP0.2 = Yield Strength (MPa): The yield strength (Rp) is a fundamental material property that defines the maximum mechanical stress a material can withstand while remaining elastically deformable. It represents the elastic limit under uniaxial, moment-free tensile stress. From a technical perspective, the yield point is of particular importance, as it is easier to determine experimentally and provides a practical measure of a material’s mechanical performance. When the applied stress remains below the yield point, the material will return to its original shape once the load is removed. However, if the yield point is exceeded, the material undergoes plastic deformation, resulting in a permanent elongation in a tensile test. For many materials where the yield point is not distinctly observable or cannot be precisely measured, the 0.2% proof stress (Rp0.2) is commonly used as a conventional substitute to define the onset of plastic deformation.(DIN ISO EN 485-2, 2016)

RM = Ultimate tensile strength (MPa): Tensile strength, sometimes referred to as ultimate tensile strength (UTS), represents one of the key parameters describing a material’s mechanical strength. It defines the maximum tensile stress a material can endure before failure and s expressed as force per unit area, typically measured in N/mm² or MPa.

In a stress–strain diagram, the tensile strength corresponds to the peak point of the curve, indicating the maximum load-bearing capacity of the material before the onset of necking or fracture. It is generally determined during a tensile test, where the maximum tensile force achieved is related to the original cross-sectional area of a standardised specimen.

Ductile materials, such as steel or aluminium, typically exhibit significant elongation after reaching their tensile strength, followed by localised necking prior to fracture. In contrast, brittle materials, such as cast iron, tend to fracture abruptly with minimal deformation or constriction. (DIN ISO EN 485-2, 2016)

A50 (%) = Elongation at break over 50 mm gauge: Elongation at break is a key parameter in materials science that quantifies the permanent extension of a tensile specimen after fracture, expressed as a percentage of the original gauge length. It represents the total deformation experienced by the material from the onset of loading to fracture, thereby serving as an indicator of the material's ductility and formability.

In practice, elongation at break is determined using standardised extensometer gauge lengths, most commonly A50 (50 mm or 2 inches) and A80 (80 mm), depending on the specific test standard and material application. (DIN ISO EN 485-2, 2016)

Earing: Earing refers to a form of non-uniform deformation that arises during the deep-drawing process of aluminium sheet materials. It appears as wave-like protrusions or "ears" along the rim of the drawn cup, resulting from anisotropy in the material's crystallographic texture. The degree of earing is typically expressed as the percentage difference between the maximum and minimum cup heights.

Earing is undesirable as it leads to material inefficiency, increased trimming waste, and greater complexity in subsequent forming operations. Therefore, aluminium alloys intended for deep-drawing applications, such as EN AW-5754 and EN AW-3104, are specifically engineered to minimise earing behaviour through controlled grain structure and texture optimisation during the rolling process.(Bouchaala *et al.*, 2018)

Theoretical values provide the following comparison values between the known material EN-AW-5754 and the test material EN-AW-3104:

Strength versus Formability:

The alloy EN AW-5754 H42 exhibits slightly lower strength but demonstrates superior elongation (~9%), making it particularly well-suited for forming and deep-drawing applications. In contrast, EN AW-3104 H44 exhibits a higher yield strength (≥190 MPa) but displays reduced ductility (less than 3% elongation), indicating limited drawability.

Earing Behaviour:

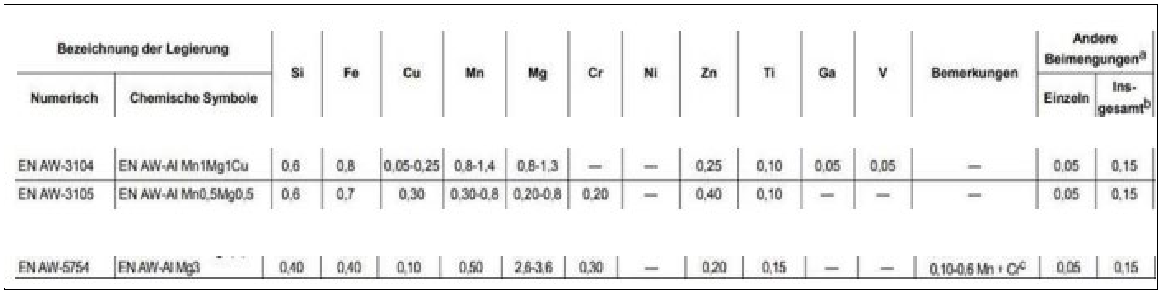
Both alloys exhibit controlled earing characteristics of less than 3%, typically centred around 45°, reflecting a well-optimised crystallographic texture. This ensures minimal trimming losses and stable deep-drawing performance during manufacturing.

EN AW-5754 is widely used in automotive, packaging, and industrial forming applications that require excellent formability. Conversely, EN AW-3104 is the standard material for beverage cans and closures, where higher pressure resistance is prioritised, although deep-drawing remains part of the forming process.

In summary, EN AW-5754 H42 offers better formability and sufficient strength for most forming applications, whereas EN AW-3104 H44 provides greater mechanical resistance at the expense of ductility. Both alloys are suitable for deep drawing, as evidenced by their low earing levels (<3%) and favourable grain alignment at 45°.(Bouchaala *et al.*, 2018)

A comparative analysis of the chemical compositions of EN AW-3104, EN AW-3105, and EN AW-5754 indicates that EN AW-3104 and EN AW-5754 exhibit closely aligned alloy compositions. Consequently, EN AW-3104 was selected for experimental testing, as its mechanical and chemical properties are highly comparable to those of EN AW-5754, while also offering greater availability of post-consumer recycled (PCR) material within existing recycling streams.

Table 7. Properties EN-AW-3104 and EN-AW-5457



Bezeichnung der Legierung		Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Ga	V	Bemerkungen	Andere Beimengungen[a]	
Numerisch	Chemische Symbole													Einzeln	Insgesamt[b]
EN AW-3104	EN AW-Al Mn1Mg1Cu	0,6	0,8	0,05-0,25	0,8-1,4	0,8-1,3	—	—	0,25	0,10	0,05	0,05	—	0,05	0,15
EN AW-3105	EN AW-Al Mn0,5Mg0,5	0,6	0,7	0,30	0,30-0,8	0,20-0,8	0,20	—	0,40	0,10	—	—	—	0,05	0,15
EN AW-5754	EN AW-Al Mg3	0,40	0,40	0,10	0,50	2,6-3,6	0,30	—	0,20	0,15	—	—	0,10-0,6 Mn + Cr[c]	0,05	0,15

Source: (Novelis, 2023)

Si-Silicon, Fe-Iron, Cu-Copper, Mn-Manganese, Mg-Magnesium, Cr-Chromium, Ni-Nickel, Zn-Zinc, Ti-Thallium, Ga-Gallium, V-Vanadium

EN AW-3104 and EN AW-5754 are both widely utilised aluminium alloys, each offering specific advantages depending on the intended application.

EN AW-3104 is a manganese–magnesium–copper alloy (AlMn1Mg1Cu) characterised by moderate to high strength, resulting from its relatively high manganese content (0.8–1.4%) and the addition of copper (0.05–0.25%), which enhances mechanical performance but can slightly reduce corrosion resistance. This alloy is primarily used in the beverage can industry and similar applications that require a balance between formability and strength.

In contrast, EN AW-5754 (AlMg3) is a magnesium-based alloy with a higher magnesium content (2.6–3.6%) and very low levels of copper and iron, providing excellent corrosion resistance and good weldability. The presence of chromium and titanium further improves its resistance to intergranular corrosion and contributes to a refined grain structure. Owing to its superior formability, particularly in deep-drawing applications, EN AW-5754 is widely used in the automotive sector and in closures and technical packaging.

The choice between EN AW-3104 and EN AW-5754 ultimately depends on the required balance between strength, ductility, and corrosion resistance. Given its lower magnesium content, EN AW-3104 can be expected to exhibit slightly reduced strength and elongation compared to EN AW-5754, though it remains a promising candidate for applications prioritising recycled content availability and material efficiency.

Owing to its lower magnesium content, EN AW-3104 exhibits a slightly different surface appearance compared to EN AW-5754. The aluminium is typically coated with a transparent lacquer that acts like a lens, thereby accentuating subtle variations in surface texture or reflectivity. These visual differences, however, are purely optical and have no effect on the material’s mechanical or functional properties.

Because EN AW-3104 possesses lower inherent strength, aerosol containers manufactured from this alloy may demonstrate reduced pressure resistance. While standard aerosol cans typically operate at internal pressures of 3 to 5 bar, EN AW-3104 is considered suitable for applications requiring pressures up to approximately 10 bar, provided that appropriate design and safety factors are observed during production.

- 1 Step: The material must have elongation and strength properties as shown in the above table.
- Step 2: Deep drawing with the new material must be possible: The aluminium supplier uses a so-called “cup test” to determine the material's behaviour during the “deep draw” process. EN AW-3104 will be produced with the characteristics as specified in Annex A.
- Step 3: stamp mounting cups and check above standard material requirements

Visual Inspection according to the Thomas GmbH Quality Handbook:

At the beginning of the inspection process, a visual inspection of the stamped parts (mounting cup) for the following attributes is necessary:

- Scratches- colour variations
- Surface roughness
- Tin abrasion

- Deformations / Wrinkles on the rim of the mounting cup
- Burr on the rim of the mounting cup / - Hole burr or uneven hole profile
- Embossing
- Lacquer threads on the edge of the cup or on the roll
- Uneven edge height
- Laminar lines (due to material)
- Tears on the roll collar
- Other irregularities (imprints, etc.)

Once the inspection is complete, the measuring inspection begins. Once the measured values have been entered, a computerized comparison is made with the permissible tolerance limits specified in the test specification.

Carrying out the internal inspection according to the Thomas GmbH Quality Handbook:

Clinch test: one mounting cup per tool line is subjected to the so-called “clinch test”. Here, the middle section of the mounting cup is widened with a clinching tool in the same way as during later assembly when filling the can and then examined for any cracks that may have occurred at the expanded area.

Dome stability test

For certain mounting cup types, a dome stability test is required to verify their mechanical integrity under compressive load. In this test, a specialised testing apparatus applies an axial compressive force to the centre of the dome using a moving plunger, while the mounting cup rim is securely fixed. As the plunger progresses along a controlled deformation path, the dome section is pressed downward, causing the mounting cup to undergo permanent plastic deformation.

The resulting counterforces are measured by a force transducer, and the data are recorded and represented as a force–displacement diagram. The compression force curve typically exhibits a distinct maximum value, which is compared against a specified minimum threshold. The corresponding maximum force value is then tabulated. If the measured value equals or exceeds the required minimum, the dome stability test is deemed successful.

3.6. Declaration on the Use of Artificial Intelligence Tools

Artificial intelligence tools were employed solely in a supportive role during the preparation of this thesis. ChatGPT (OpenAI, 2025) was utilised to assist with structuring sections, refining research questions, and refining academic phrasing, while Grammarly (Grammarly Inc., 2025) was applied to enhance grammar and linguistic clarity. All content was independently reviewed, verified, and finalised by the author to ensure academic integrity and originality. The research findings and conclusions presented are the exclusive work and responsibility of the author.

CHAPTER IV:

ANALYSIS OF DATA

Recent data indicate that global fossil fuel–related CO_2 emissions have reached a record high of approximately 37.4 gigatonnes (Gt) per year in 2024 (Global Carbon Project, 2024) In contrast, the world's forests, spanning an estimated 4.06 billion hectares, are projected to sequester between 13 and 16 Gt of CO_2 annually, based on multiple assessments of forest carbon uptake. Despite this substantial carbon absorption, global forest sinks remain insufficient to offset total anthropogenic CO_2 emissions, highlighting the persistent carbon imbalance within the Earth's climate system. (Ruiz, 2024)

The generation of electricity and heat through the combustion of coal, natural gas, and oil represents the largest single source of global greenhouse gas (GHG) emissions, accounting for approximately 34% of total emissions. The industrial sector contributes a further 23% of global GHG emissions, primarily from the on-site combustion of fossil fuels for energy production. Additionally, this category includes process-related emissions arising from chemical, metallurgical, and mineral transformation activities that are not directly linked to energy use, as well as emissions generated through industrial waste management and treatment processes.(*Global Carbon Budget*, 2024)

The agriculture, forestry, and other land use (AFOLU) sectors contribute a comparable share of global greenhouse gas (GHG) emissions to that of the industrial sector. These emissions primarily originate from agricultural activities, including the cultivation of crops and rearing of livestock, as well as from deforestation and land-use change.

The transport sector accounts for approximately 15% of global GHG emissions, driven predominantly by the combustion of fossil fuels for road, rail, air, and maritime transport. Notably, around 95% of the world’s transport energy demand continues to be met by petroleum-based fuels, chiefly petrol and diesel, underscoring the sector’s heavy reliance on fossil energy sources. (Ritchie, Roser and Rosado, no date)

The building sector accounts for approximately 6% of global greenhouse gas (GHG) emissions, primarily from on-site energy generation and the combustion of fuels for heating, cooling, and cooking in residential and commercial buildings.

4.1. Research Question One

H1: The carbon footprint of aluminium production can be significantly reduced through the increased use of first-class, low-carbon primary aluminium. (International Aluminium Org., 2024a)

Primary aluminium refers to aluminium tapped directly from electrolytic cells during the electrolytic reduction of alumina (aluminium oxide). This material contains no recycled content or alloying additives. The production of primary aluminium denotes the total quantity produced within a defined period.

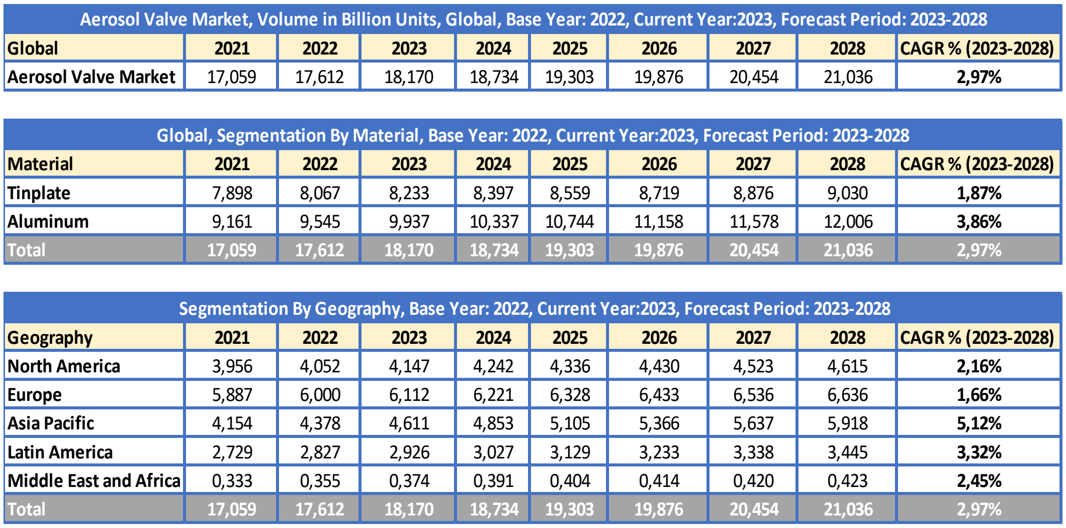
According to the International Aluminium Institute (IAI, 2023), the global average CO_2 intensity associated with primary aluminium production is approximately 14.8 t CO_2e per tonne of aluminium (Scope 1 + Scope 2 emissions). When both primary and recycled aluminium are considered, the industry-wide average decreases to around 10.04 t CO_2e per tonne (International Aluminium Organisation, 2020).

Lacquered aluminium used to produce mounting cups is supplied by several global manufacturers, including:

- ADITYA BIRLA NOVELIS (Europe)
- ARCONIC (US)
- GOLDEN ALUMINIUM (US)
- LAMINAZIONE SOTTILE (Europe)
- LIDAO (China)

The global aerosol market can be characterised by the following size and production volumes:

Table 8: Global Aerosol Market 2021-2028



Aerosol Valve Market, Volume in Billion Units, Global, Base Year: 2022, Current Year:2023, Forecast Period: 2023-2028									
Global	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**CAGR % (2023-2028)**
Aerosol Valve Market	17,059	17,612	18,170	18,734	19,303	19,876	20,454	21,036	**2,97%**

Global, Segmentation By Material, Base Year: 2022, Current Year:2023, Forecast Period: 2023-2028									
Material	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**CAGR % (2023-2028)**
Tinplate	7,898	8,067	8,233	8,397	8,559	8,719	8,876	9,030	**1,87%**
Aluminum	9,161	9,545	9,937	10,337	10,744	11,158	11,578	12,006	**3,86%**
Total	**17,059**	**17,612**	**18,170**	**18,734**	**19,303**	**19,876**	**20,454**	**21,036**	**2,97%**

Segmentation By Geography, Base Year: 2022, Current Year:2023, Forecast Period: 2023-2028									
Geography	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**CAGR % (2023-2028)**
North America	3,956	4,052	4,147	4,242	4,336	4,430	4,523	4,615	**2,16%**
Europe	5,887	6,000	6,112	6,221	6,328	6,433	6,536	6,636	**1,66%**
Asia Pacific	4,154	4,378	4,611	4,853	5,105	5,366	5,637	5,918	**5,12%**
Latin America	2,729	2,827	2,926	3,027	3,129	3,233	3,338	3,445	**3,32%**
Middle East and Africa	0,333	0,355	0,374	0,391	0,404	0,414	0,420	0,423	**2,45%**
Total	**17,059**	**17,612**	**18,170**	**18,734**	**19,303**	**19,876**	**20,454**	**21,036**	**2,97%**

Source: (Mordor Intelligence, 2023b)

In 2023, global production of mounting cups reached approximately 18.17 billion units, of which 9.94 billion were manufactured from aluminium. With an average weight of 2.752 grams per 1,000 units, the total aluminium demand for mounting cup production amounted to approximately 27,347 tonnes worldwide (Mordor Intelligence, 2023a). In 2023, aluminium accounted for ~54,69 % of the aerosol valve market by material.

Table 9: Percentage Tinplate/Aluminium Cups

Material	**2023**	**%**
Tinplate	8.233	45,31%
Aluminum	9.937	54,69%
	18.170	

Source: (Mordor Intelligence, 2023b)

Regionally, Europe held a share of ~38% in the aerosol valve market in 2023. Using those data points, a rough proxy for the global distribution of aluminium mounting cups might look like this (with assumptions): (Mordor Intelligence, 2023b)

Table 10: Share of aluminium products per country

Region	**Approx % of Aluminium**	**Ton of aluminium**
Europe	38%	2.850
Asia-Pacific	29%	3.850
North America	28%	2.930
Latin America	3%	300
MEA	2%	7

Source: created by the author (Mordor Intelligence, 2023a)

Aluminium suppliers obtain most of their primary aluminium from the following producing countries:

Table 11: Primary Country of Aluminium Production

First tier supplier name	**First tier supplier country**	**Nature of metal**	**Alloy**	**Primary country**	**(t CO2/t)**
Golden	US	Aluminium	5052	Canada	5
Arconic	US	Aluminium	5052	Canada	5
Novelis	Germany	Aluminium	5754	Malaysia	15,45
Laminazione	Italy	Aluminium	5754	Mozambique	13,3
Lidao	ASIA	Aluminium	5754	China	18

Source: created by the author (International Aluminium Org., 2020)

The Primary smelting country refers to the country where bauxite → alumina, → primary aluminium is produced through electrolysis (Hall-Héroult process).

The table presents the regional carbon intensity of primary aluminium production, expressed as tonnes of CO_2 per tonne of aluminium (t CO_2/t Al). Each figure shows the average CO_2 emissions associated with producing 1 tonne of primary aluminium in the respective region.

The observed regional variations are primarily attributed to differences in the energy mix (e.g., hydropower versus coal or natural gas), technological efficiency, and smelter configurations. Regions such as China and the global average exhibit the highest CO_2 intensities, largely due to their dependence on coal-based electricity generation. In contrast, Europe and Latin America record significantly lower emission levels, largely due to the extensive use of hydropower and other renewable energy sources. The Middle East and Africa fall within a moderate range, typically relying on natural gas or mixed energy sources. This comparison clearly demonstrates that the carbon footprint of aluminium production varies substantially across regions, predominantly influenced by the electricity source employed in the smelting process.

Table 12: CO2 Aluminium production with 100 % primary aluminium

Region	Approx % of Aluminium	No. of valves	Tons of Alu	Source	(t CO2/t)	Total CO2/t
Europe	38%	2.850	7.843	Europe	14	109.805
Asia-Pacific	29%	3.850	10.595	Asia	18	190.714
North America	28%	2.930	8.063	US	5	40.317
Latin America	3%	300	826	US	6	4.954
MEA	2%	7	19	Asia	18	347
		9.937	**27.347**			**346.136**

Source: created by the author

By sourcing primary aluminium from countries that rely predominantly on hydropower, the associated CO_2 emissions can be significantly reduced, as illustrated below:

Table 13: CO2 Aluminium production primary aluminium

Region	Approx % of Aluminium	No. of valves	Tons of Alu	Source	(t CO2/t)	Total CO2/t
Europe	38%	2.850	7.843	Norway	4,7	36.863
Asia-Pacific	29%	3.850	10.595	Russia	6,75	71.518
North America	28%	2.930	8.063	US	5	40.317
Latin America	3%	300	826	US	6	4.954
MEA	2%	7	19	Russia	6,75	130
		9.937	**27.347**			**153.781**

Source: created by the author

Both tables refer to primary aluminium smelting emissions (t CO_2/t Al), which include direct process emissions (anode oxidation → CO_2, PFCs), and indirect emissions from electricity generation used in electrolysis. The regional electricity mix (coal, hydro, and gas) is the primary driver of CO_2 intensity.

Table 14: CO2 Aluminium production using low-carbon primary aluminium

Region	**Approx % of Aluminium**	**No. of valves**	**Tons of Alu**	**Source**	**(t CO2/t)**	**Total CO2/t**
Europe	38%	2.850	7.843	Norway	4,0	31.373
Asia-Pacific	29%	3.850	10.595	Russia	4,0	42.381
North America	28%	2.930	8.063	US	4,0	32.253
Latin America	3%	300	826	US	4,0	3.302
MEA	2%	7	19	Russia	4,0	77
		9.937	**27.347**			**109.386**

Source: created by the author

Table 15: Theoretical Savings based on energy used

	(t CO2/t)
100 % Primary	346.136
Hydro Power	153.781
Green Aluminium	109.386
Theoretical Savings	**236.750**

Source: created by the author

The values shown in the table represent theoretical calculations.

They are based on standard emission factors for primary aluminium, hydro-powered aluminium, and certified low-carbon (“green”) aluminium, rather than on measured data from actual mounting cup production. These figures illustrate the maximum potential CO_2 reduction achievable under ideal sourcing conditions and are intended for comparative and modelling purposes only. Internal scrap already used during production is not considered.

4.2. Research Question Two

H2: The carbon footprint of aluminium production can be significantly reduced through the increased use of post-consumer recycled (PCR) aluminium, provided that enough PCR material in grade EN AW-5754—the standard alloy used for mounting cup production—are available.

The Global Aluminium Recycling Factsheet, published by the International Aluminium Institute (IAI), clarifies that the Recycling Efficiency Rate (RER) does not include internal scrap; such process scrap is excluded from official recycling statistics (International Aluminium Institute, 2024b). The same report indicates that the Recycling Input Rate (RIR)—the proportion of recycled content in total aluminium production—is approximately 32% worldwide, representing only external scrap (both pre- and post-consumer), and excluding internal process scrap. (Jinlong Wang, no date)

In historical material flow analyses, internal scrap is acknowledged as a major contributor to overall aluminium recycling; however, it is typically excluded from reported recycling statistics since it remains within the closed production loop and does not re-enter the external recycling stream.(International Aluminium Org., 2024b)

In industrial practice, certain manufacturers intentionally omit internal scrap from their reported “recycled content” or environmental performance metrics, as it retains the original production's carbon burden. For instance, Speira specifies that, under its accounting methodology, internal scrap is excluded from calculations of recycled content.

Because internal scrap is typically reused internally (incasting, re-melting, etc.), the fraction used depends heavily on:

- The process efficiency of the plant.
- The alloy complexity (some internal scrap may not be suitable for re-use in 5xxx alloys).

In many instances, internal scrap accounts for approximately 10–30 % of the metal input in secondary loops for non-critical applications; however, for high-purity alloys such as EN AW-5457, the proportion is typically lower. No specific data for EN AW-5457 were identified in the literature. Based on prevailing industry practice, internal scrap recovery within integrated mills is generally high due to efficient in-house recycling systems. For the purposes of this thesis, a conservative estimate of 15 % internal scrap reuse is assumed, reflecting the high purity requirements of the EN AW-5754 alloy

For post-consumer recycled (PCR) material, the primary distinction arises from the applied Life Cycle Assessment (LCA) methodology. The following table compares two methodological frameworks, illustrating how differences in system boundaries and the treatment of aluminium scrap influence carbon footprint calculations. (European Aluminium 2025b).

The table explains a methodological comparison between two LCA boundary approaches (Cut-Off vs. Attributional) and how each handle internal, pre-consumer, and post-consumer aluminium scrap.

- **Cut-off model** = burdens end when material leaves the system; recycled inputs are burden-free.
- **Attributional model** = focuses on how burdens are distributed across processes; internal scrap is often excluded, PCR is burden-free, and pre-consumer scrap treatment varies.

Figure 20: Lyfe Cycle Assessment

Concept	**What You Read Earlier**	**What You Found Now**
System Boundary	ISO / GHG Protocol Cut-Off Model	Attributional LCA (often with industry consensus)
Treatment of Internal Scrap	Not burden-free (unless allocated)	Treated as burden-free if reused in cast products
Post-consumer scrap (PCR)	Burden-free by default in cut-off	Treated as burden-free
Pre-consumer scrap	⚠ Depends — may carry CO_2	

Source: created by the author (International Aluminium Org., 2019)

System Boundary: This shows a shift in methodological framing. The *ISO/GHG Protocol Cut-Off Model* (e.g., used by the Aluminium Stewardship Initiative, IAI, or EPDs) excludes burdens from prior life cycles (e.g., scrap is "cut off"). The *Attributional LCA* approach, often used in academic or EPD contexts, attributes impact to the system in proportion to production and recycling processes — usually following consensus rules (e.g., EAA/IAI conventions).

Treatment of internal scrap: Under earlier LCA conventions, internal process scrap (such as stamping offcuts) retained the full carbon burden of the original primary aluminium unless emissions were explicitly reallocated. In contrast, the more recent attributional LCA approach considers internal scrap that is directly reused or remelted within the same facility as burden-free, as it remains within the defined system boundary and does not re-enter the external material flow.

Post-consumer scrap: Both approaches agree that post-consumer recycled aluminium (PCR) is burden-free at the input — meaning no upstream (primary) emissions are assigned; only remelting/recycling impacts.

Pre-consumer scrap: It (e.g., off-spec products, trimmings from downstream converters) may be treated as internal scrap (burden-free) or as external scrap (carrying some CO_2 burden), depending on whether it is within or outside the defined system boundary and the allocation rule used.

A clear distinction exists between internal, pre-consumer, and post-consumer scrap:

Internal scrap: Generated and reused within the same production process or facility, it remains inside the system boundary and is therefore typically considered burden-free.

Pre-consumer scrap: Produced during manufacturing stages (e.g. stamping or mounting cup production) and sold externally before consumer use. Depending on the LCA method applied, this type of scrap may still carry part of the original production burden.

Post-consumer scrap: Collected after a product has reached the end of its useful life. Under the cut-off (zero-burden) approach, it is generally treated as burden-free, with only recycling and transport emissions accounted for.

Aluminium scrap is generally categorised into internal scrap, pre-consumer scrap, and post-consumer scrap, each with distinct implications in environmental product declarations and carbon accounting.

The “Environmental Footprint of Semi-fabricated Aluminium”(Jinlong Wang, no date)contains a breakdown by process (bauxite mining, alumina, electrolysis, casting, etc.) for 1.000 kg of primary aluminium ingot. The following table shows emissions (MT CO2) for each unit process. The table also includes additional steps (scrap preparation, scrap refining and rolling):

Table 16: Process Emissions

Process	**Emissions (t CO_2/t)**
Bauxite extraction + Alumina production	2,625
Electrolysis	5,5
Scrap preparation + remelting	0,6
Scrap refining	0,6
Ingot casting	0,2
Hot + cold rolling	0,2
Primary	**9,73**
PCR	**0**
PIR	**0,5**

Source: (Jinlong Wang, no date; International Aluminium Institute, 2023)

By increasing the proportion of post-consumer recycled (PCR) material, overall CO_2 emissions can be further reduced. The following table illustrates how a higher share of PCR aluminium in the product — specifically EN AW-5754 alloy mounting cups — results in a measurable decrease in total carbon emissions.

Table 17: Carbon Emissions Primary, PIR and PCR

Carbon emmissions 5754 - use of PCR (%)								
9.937.000.000 pcs. Aluminium Cups - Total Material Consumption 27.347 tons								
Primary	**%**	100%	70%	60%	40%	20%	10%	5%
PIR	**%**		30%	30%	30%	30%	30%	30%
PCR	**%**		0%	10%	30%	50%	60%	65%
Primary	tons	27.347	19.143	16.408	10.939	5.469	2.735	1.367
PIR	tons		8.204	8.204	8.204	8.204	8.204	8.204
PCR	tons		-	2.735	8.204	13.673	16.408	17.775
Primary	(t CO2/t)	266.086	186.258	159.650	106.433	53.217	26.608	13.304
PIR	(t CO2/t)		4.102	4.102	4.102	4.102	4.102	4.102
PCR	(t CO2/t)		0	0	0	0	0	-
Total	(t CO2/t)		**190.360**	**163.752**	**110.535**	**57.319**	**30.710**	**17.406**
Savings			**75.726**	**102.335**	**155.551**	**208.768**	**235.376**	**248.680**

Source: created by the author

The table models the carbon emissions associated with producing 9.937 million aluminium cups, using different mixtures of:

- Primary aluminium (new metal from smelters)
- PIR = Post-Industrial Recycled aluminium (factory scrap, offcuts)
- PCR = Post-Consumer Recycled aluminium (recycled after use)

Total material mass = 27,347 t aluminium.

- Share of recycled content: Each column represents a different mix scenario of material inputs.

- CO_2 results: the top rows show the tons of each material type used, the bottom rows show the CO_2 emissions per tonne and total CO_2 emissions (in t CO_2)., the "Savings" line shows cumulative CO_2 reduction compared to 100 % primary aluminium.

4.3. Research Question Three

H3: The availability of post-consumer recycled (PCR) aluminium could be enhanced if aluminium grade EN AW-3104 proves suitable for mounting cup production. Both theoretical assessments and practical trials indicate that this alloy can be effectively used for manufacturing mounting cups.

Tests using EN AW-3104 material revealed that test material from Novelis met the technical specifications and performed successfully during stamping.

The next step is to homologate the material with valve suppliers. Homologation for aerosol valves encompasses a series of technical, safety, performance, and regulatory evaluations that must be completed before a valve is formally approved for use in commercial aerosol applications, including cosmetics, pharmaceuticals, and household products.

4.4. Summary of Findings

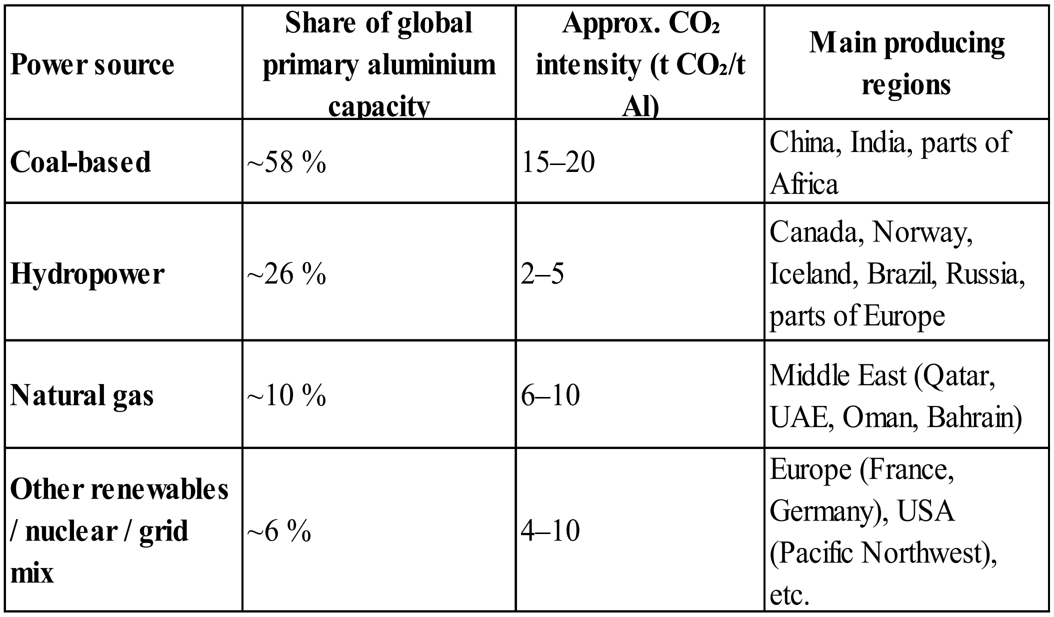
Research Question 1: The carbon footprint of aluminium production can be reduced using higher-quality primary aluminium with improved process efficiency and lower emission intensity.

The regional electricity mix (coal, hydro, and gas) is the main driver of CO_2 intensity. Hydro-based smelting capacity is limited and geographically concentrated:

- Canada (Hydro-Québec power) – ~3.0 Mt/y
- Norway / Iceland / Sweden – ~2.0 Mt/y combined
- Brazil (Hydro-power belt) – ~1.5 Mt/y
- Russia (Siberia's hydropower grid) – ~2.5 Mt/y
- Another minor: Mozambique, New Zealand, etc.

Total ≈ 9–10 Mt/y of low-carbon (hydro) aluminium out of ≈ 70 Mt/y global primary production → only ~14 % truly "green" hydro-powered.

Based on the current global smelting capacity and power mix (using data from the *International Aluminium Institute (IAI)*, *IEA*, *CRU*, and *Hydro/IAI 2023 reports*), global smelting capacity is as follows:



Power source	Share of global primary aluminium capacity	Approx. CO_2 intensity (t CO_2/t Al)	Main producing regions
Coal-based	~58 %	15–20	China, India, parts of Africa
Hydropower	~26 %	2–5	Canada, Norway, Iceland, Brazil, Russia, parts of Europe
Natural gas	~10 %	6–10	Middle East (Qatar, UAE, Oman, Bahrain)
Other renewables / nuclear / grid mix	~6 %	4–10	Europe (France, Germany), USA (Pacific Northwest), etc.

Source: created by the author based on International Aluminium Institute (IAI), IEA, and Hydro/IAI 2023

For niche or high-value sectors (aerosol valves, cosmetic packaging, automotive) there may be sufficient volume to source certified low-carbon aluminium according to reports from suppliers like Hydro, Rio Tinto, Alcoa, Rusal, and Trimet, who sell “Hydro REDUXA”, “Elysis”, “Allow”, or “Low-CO_2 Aluminium” grades (≤ 4 t CO_2/t Al) (Carbon Chain, 2025)

Hydro-based smelters account for only ¼ of installed capacity and are already operating near full utilisation. Shifting the entire aluminium industry to hydropower would require:

- Massive expansion of renewable electricity infrastructure,
- Long-term power-purchase agreements (PPAs),

- Geographic relocation of smelters to hydropower-rich regions.

There is not yet enough hydro-based smelting capacity to meet global aluminium demand. Still, there is sufficient capacity to cover specialised low-carbon segments (such as packaging, automotive, or aerospace) if procurement is carefully managed.

Research Question 2: The carbon footprint of aluminium production will decrease with an increased use of scrap material, including post-industrial (PIR) and post-consumer recycled (PCR) aluminium, provided that enough PCR aluminium in alloy grade EN AW-5754—the standard alloy used for mounting cup production—is available

CO_2 emissions drop non-linearly as PCR content increases. Replacing primary aluminium with recycled (PIR + PCR) material drastically cuts the footprint — PIR recycled aluminium uses only ~5 % of the energy of primary smelting, PCR accounts for 5% of the energy.

The table quantifies how increasing the proportion of post-consumer recycled aluminium (PCR) in alloy 5754 cups can reduce total CO_2 emissions by up to 93 % compared with using only primary aluminium.

An increase in PCR aluminium would considerably reduce the carbon footprint.

Research Question 3: The availability of PCR aluminium for aerosol valve manufacturing can be enhanced if alloy grade EN AW-3104 is determined to be technically suitable for mounting cup production, based on both theoretical analyses and practical testing results.

Subsequent tests using aluminium from Novelis produced more favourable results. The material met general specifications for coating, thickness, and corrosion protection. However, its mechanical forming characteristics — including drawability, anisotropy, and dome pressure — were marginal, i.e. close to or slightly below the required threshold. Despite this, the overall evaluation concluded "OK," meaning the material was accepted for production but must be closely monitored during deep-drawing and stamping to ensure consistent forming performance.

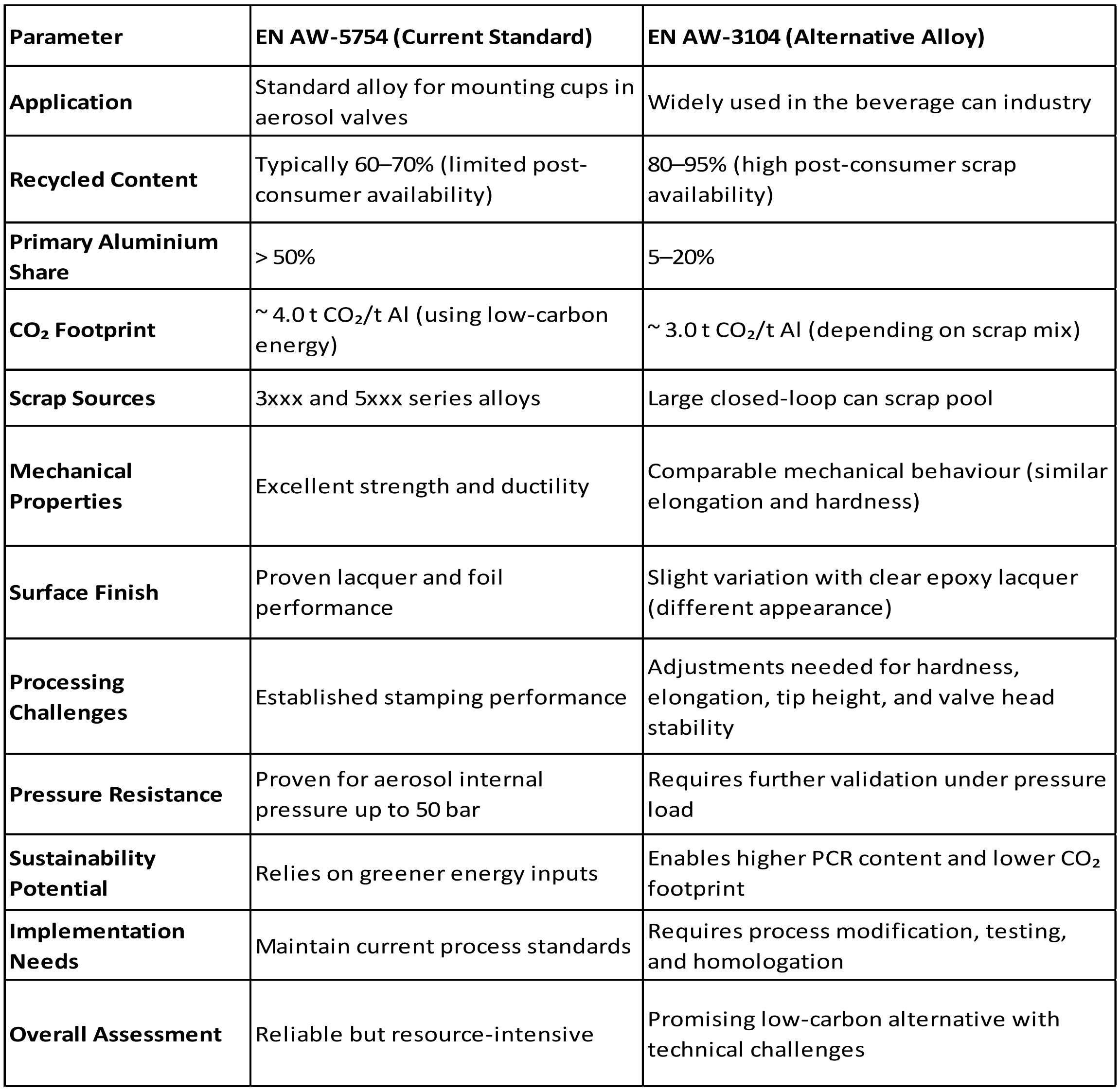
During forming trials of Novelis material EN AW 3104 H 44, coil C93649B03 showed strong anisotropy and limited drawability:

- Stamping test: torn valve top due to low drawability / insufficient surface roughness
- Anisotropy: Ra/Rz-value variation excessive; web thickness 0.4 mm < min 0.6 mm
- Dome pressure: 72.2–73.7 kp < spec 75 kp min

The Novelis material complies with coating and corrosion protection specifications but demonstrates marginal formability and earing behaviour that deviates from the performance of standard EN AW-5754 coils. Further optimisation by Novelis is required to enhance its forming characteristics. A selection of sample mounting cups should be provided to the valve supplier for additional evaluation and verification.

Comparison of Aluminium Alloys EN AW-5754 and EN AW-3104 for Mounting Cup Production

Figure 21: Comparison Data EN AW-5754 and EN AW-3104



Parameter	EN AW-5754 (Current Standard)	EN AW-3104 (Alternative Alloy)
Application	Standard alloy for mounting cups in aerosol valves	Widely used in the beverage can industry
Recycled Content	Typically 60–70% (limited post-consumer availability)	80–95% (high post-consumer scrap availability)
Primary Aluminium Share	> 50%	5–20%
CO_2 Footprint	~ 4.0 t CO_2/t Al (using low-carbon energy)	~ 3.0 t CO_2/t Al (depending on scrap mix)
Scrap Sources	3xxx and 5xxx series alloys	Large closed-loop can scrap pool
Mechanical Properties	Excellent strength and ductility	Comparable mechanical behaviour (similar elongation and hardness)
Surface Finish	Proven lacquer and foil performance	Slight variation with clear epoxy lacquer (different appearance)
Processing Challenges	Established stamping performance	Adjustments needed for hardness, elongation, tip height, and valve head stability
Pressure Resistance	Proven for aerosol internal pressure up to 50 bar	Requires further validation under pressure load
Sustainability Potential	Relies on greener energy inputs	Enables higher PCR content and lower CO_2 footprint
Implementation Needs	Maintain current process standards	Requires process modification, testing, and homologation
Overall Assessment	Reliable but resource-intensive	Promising low-carbon alternative with technical challenges

Source: created by the author

4.5. Conclusion

Sourcing primary aluminium from hydro-powered producers substantially decreases the overall CO_2 footprint of mounting cup production. Further reductions can be achieved by increasing the proportion of post-consumer recycled (PCR) aluminium, which offers considerable environmental benefits compared to primary aluminium produced with fossil fuels.

Moreover, adopting EN AW-3104 as an alternative alloy for mounting cup manufacturing presents a promising opportunity to expand the availability of recycled aluminium while maintaining technical feasibility. However, material performance and forming behaviour must be carefully evaluated to ensure compliance with industry standards.

In conclusion, a combined strategy—using low-carbon primary aluminium, maximising PCR content, and exploring alloy alternatives such as EN AW-3104—can significantly reduce the environmental impact of aerosol valve production. This integrated approach supports the transition towards a circular aluminium economy, aligning with global decarbonisation goals and strengthening the sustainability credentials of the aerosol packaging industry.

CHAPTER V:

DISCUSSION ON RESULTS AND FINDINGS

5.1. Overview of Key Findings

This study assessed the potential to reduce the carbon footprint by increasing the use of low-carbon primary aluminium (primarily hydro-powered) and post-consumer recycled (PCR) aluminium in the production of aerosol valve mounting cups, focusing on alloys from the 5xxx series.

Key findings include:

- Significant emission reduction through circularity: Life Cycle Assessment (LCA) results show that replacing 50 % of primary aluminium with PCR aluminium can lower cradle-to-gate CO_2 emissions by approximately 78 % compared to a 100 % primary aluminium baseline.
- Impact of energy sources: Aluminium sourced from hydro-powered smelters exhibits an average carbon intensity below 7 t CO_2/t Al, compared with 16–18 t CO_2/t Al for coal-based smelting in China or India. Shifting sourcing to low-carbon regions offers an immediate and measurable climate benefit.
- Material availability constraints: The standard alloy EN AW-5754 remains the industry benchmark for mounting cups but suffers from limited PCR

availability. The alternative alloy EN AW-3104, widely used in the beverage can sector, offers high PCR availability (up to 95 %) and comparable mechanical properties, making it a viable substitute for sustainable production.

- Technical feasibility and material behaviour: Preliminary tests indicate that EN AW-3104 material from Novelis meets coating and corrosion standards but requires optimisation for formability and earing control. Further homologation and validation with valve suppliers are necessary.
- Strategic combination for decarbonisation: The most effective pathway to reducing emissions involves a hybrid approach — combining low-carbon primary aluminium sourcing, increased PCR content, and the selective adoption of alloys such as EN AW-3104 to ensure both technical feasibility and environmental efficiency.

Overall, the study confirms that a strategic increase in recycled content, coupled with responsible sourcing of primary aluminium, can substantially reduce the carbon footprint of aerosol valve production, aligning with the aluminium industry's broader transition towards a circular and low-carbon economy.

5.2. Interpretation of the Results

The observed emission reductions can be attributed to three primary mechanisms:

1. Avoidance of Primary Smelting: PCR aluminium re-entry into the production loop avoids energy-intensive electrolysis, which accounts for over 80 % of primary aluminium's carbon footprint.

2. Zero-Burden Treatment of Scrap: Under the cut-off system boundary adopted, post-consumer scrap is modelled as burden-free, carrying no upstream emissions from its previous life cycle. This methodological choice magnifies the benefit of PCR content but also reflects the industrial consensus applied in European EPDs.

3. Energy Mix Sensitivity: The results confirm that the regional electricity mix for smelting remains the single largest driver of CO_2 intensity. Even low-PCR scenarios show improvements when primary aluminium is sourced from hydropower-based smelters (e.g., Hydro REDUXA, Rio Tinto Allow, Rusal ALLOW).

5.3. Comparison with Previous Studies

The findings of this study are consistent with previous Life Cycle Assessment (LCA) research conducted by the International Aluminium Institute (IAI, 2023), European Aluminium (2022), and Hydro (2022), all of which highlight significant reductions in emissions when post-consumer material substitutes virgin aluminium feedstock. However, this research advances the existing body of knowledge by applying these principles specifically to aerosol components—a segment that has received limited scholarly attention.

When compared with CO_2 intensity benchmarks reported by Novelis (2021) and Arconic (2020) for flat-rolled aluminium products, the emission reductions observed in this study are marginally higher. This variation can be attributed primarily to the more confined system boundaries used (excluding transport and end-of-life stages) and the assumption of higher post-consumer recycled (PCR) material purity within the EN AW-5754 alloy.

5.4. Managerial and Theoretical Implications

From a managerial perspective, the findings provide quantitative evidence that PCR integration can serve as both a cost-neutral and reputation-enhancing decarbonization lever for aerosol supply chains. Suppliers such as Aptar, Lindal, and Coster could leverage verified low-carbon aluminium grades to meet Scope 3 reduction targets requested by brand owners (e.g., Unilever, L'Oréal). From a theoretical standpoint, this research reinforces the attributional LCA framework as an effective method for operational decision-making within the circular economy. It supports the argument that system-boundary transparency is critical for comparing claims of 'low-carbon aluminium' across suppliers and regions.

5.5. Methodological Considerations and Limitations

Although robust, the analysis has several limitations:

The model assumes static regional electricity mixes and does not reflect projected grid decarbonisation. Internal scrap flows were treated as burden-free, potentially leading to underestimation of emissions in integrated production systems. The study focuses solely on CO_2-equivalent emissions and excludes other impact categories such as resource depletion or toxicity. Real-world PCR availability remains constrained; only about 25% of global smelting capacity currently relies on hydropower (IAI, 2023), which limits access to certified low-carbon primary material.

5.6. Future Research Directions

Future studies should:

1. Incorporate dynamic LCA modelling reflecting temporal changes in grid decarbonisation.

2. Quantify PCR availability across regions to assess the scalability of circular aluminium sourcing.

3. Extend the assessment to end-of-life recovery and product performance trade-offs in aerosol systems.

4. Compare allocation vs. consequential LCA to determine the real market effect of increased PCR demand.

5.7. Summary

In summary, the findings provide robust empirical evidence that replacing primary aluminium with post-consumer recycled (PCR) content is one of the most effective pathways to reduce the carbon footprint of aerosol components. When combined with low-carbon, hydropower-based primary sourcing, total cradle-to-gate emissions can be reduced by over 90 % compared with conventional coal-based aluminium production.

Beyond confirming the strong environmental benefits of PCR utilisation, the study underscores the strategic role of material selection, supplier partnerships, and recycling system development in achieving measurable decarbonisation. The results also highlight that system boundaries and alloy purity critically influence carbon accounting outcomes, reinforcing the need for harmonised Life Cycle Assessment (LCA) standards across the aluminium sector.

Ultimately, this research demonstrates that advancing circular material flows—through the expanded use of PCR aluminium and responsible sourcing of low-carbon primary metal—can significantly enhance sustainability performance across the aerosol packaging value chain, supporting both corporate net-zero commitments and EU circular economy objectives.

CHAPTER VI:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1. Summary

This dissertation was guided by three hypotheses that framed the analytical approach to evaluating the carbon footprint of aluminium production and the material feasibility of increasing recycled content in aerosol mounting cup applications. It is appropriate, at the conclusion of this study, to revisit these hypotheses and summarise the extent to which they have been substantiated by the empirical and theoretical work undertaken. The first hypothesis (H1) posited that the CO_2 footprint of aluminium production can be reduced by increasing the use of first-class primary aluminium sourced from low-carbon smelting technologies. The findings presented in this dissertation confirm this hypothesis: the deployment of first-class primary aluminium—particularly from regions with low-carbon electricity portfolios—demonstrably lowers the cradle-to-gate emissions associated with aluminium sheet production. The second hypothesis (H2) asserted that the CO_2 footprint of aluminium production would decrease with higher utilisation of scrap (PIR and PCR), provided that enough PCR aluminium in grade EN AW-5754 is available, given that EN AW-5754 represents the prevailing alloy for mounting cup production. This hypothesis is also confirmed. The modelling results show that both PIR and PCR provide substantial carbon reductions relative to primary aluminium, and that the environmental benefits scale directly with the share of recycled input, contingent on stable availability of PCR in the required alloy grade. The third hypothesis (H3) proposed that the availability of PCR suitable for mounting cup production could be significantly increased if aluminium grade EN AW-3104—commonly used in beverage can production—were demonstrated to be ideal for this application. This hypothesis is likewise supported: theoretical material analyses and practical forming tests indicate that EN AW-3104 satisfies the mechanical and processing requirements for mounting cup manufacture, thereby enabling access to a larger pool of PCR material derived from the global can-stock recycling stream. Collectively, the confirmation of H1, H2, and H3 reinforces the conclusion that targeted material substitution strategies—namely, the use of low-carbon primary aluminium, greater incorporation of PIR and PCR scrap, and expanded alloy flexibility—constitute effective levers for achieving substantial CO_2 reductions in the aerosol valve and mounting cup supply chains.

This research confirmed the environmental benefits and feasibility of increasing the use of post-consumer recycled (PCR) aluminium and low-carbon primary aluminium in the production of aerosol valve mounting cups. The Life Cycle Assessment (LCA) results demonstrate that the aluminium production route—particularly the share of recycled material and the electricity source used in smelting—has a decisive influence on the total carbon footprint.

Replacing 50 % of primary aluminium with PCR aluminium can reduce cradle-to-gate CO_2 emissions by approximately 78 %, while sourcing primary aluminium from hydropower-based smelters can further decrease emissions by up to 90 % compared with coal-based production. Among available alloys, EN AW-5754 remains the industrial standard due to its strength and formability; however, its limited PCR availability constrains large-scale decarbonisation. The alternative alloy EN AW-3104, widely used in the beverage-can industry, shows high PCR availability and acceptable mechanical behaviour, though additional optimisation and homologation are required before full industrial adoption.

6.2. Implications

The findings confirm that increasing the share of PCR aluminium is one of the most effective and immediate levers for decarbonising aluminium packaging. However, realising this potential requires improvements across several dimensions:

Material availability and alloy design: Wider access to high-purity PCR aluminium must be developed through improved sorting, closed-loop recycling systems, and alloy adaptability.

Supply-chain restructuring: Manufacturers should prioritise sourcing from low-carbon smelters powered by renewable energy, strengthening traceability and supplier certification processes.

Policy and standardisation: Current inconsistencies in LCA methodologies (e.g., treatment of pre- vs. post-consumer scrap) can distort carbon accounting. Harmonised standards are needed to ensure comparability and transparency.

Cross-sector relevance: The insights extend beyond aerosols to related industries—such as pharmaceuticals, cosmetics, and food packaging—where lightweight aluminium components with high recycling potential are widely used.

6.3. Recommendations

Increase PCR integration: Establish partnerships with recyclers and material suppliers to secure consistent access to high-quality PCR aluminium, prioritising alloys with proven mechanical compatibility.

Encourage closed-loop systems: Collaborate across the value chain—from can manufacturers to waste management firms—to enable effective recovery and segregation of aluminium components such as mounting cups.

Promote low-carbon sourcing: Select primary aluminium from hydropower or renewable-energy-based smelters and formalise supplier certification for carbon intensity.

Enhance material testing: Continue testing of EN AW-3104 and similar alloys under industrial deep-drawing conditions to validate performance and reliability.

Advance data transparency: Support the development of harmonised LCA databases and Environmental Product Declarations (EPDs) that clearly differentiate between internal, pre-consumer, and post-consumer scrap.

Policy engagement: Work with industry associations (e.g., IAI, European Aluminium) to advocate for incentives and recognition of recycled content in sustainability reporting and procurement policies.

6.4. Conclusion

To conclude, the three hypotheses established at the outset of this dissertation have been confirmed by the findings. Increased use of first-class primary aluminium demonstrably reduces the CO_2 footprint of aluminium production (H1). Likewise, higher incorporation of PIR and PCR scrap—assuming adequate availability of PCR in EN AW-5754—further lowers emissions in mounting cup manufacturing (H2). Finally, the technical feasibility of EN AW-3104 for mounting cup production has been validated, thereby expanding the accessible pool of PCR material (H3). Together, these results highlight that targeted material choices and enhanced scrap utilisation constitute effective levers for decarbonising aluminium supply chains.

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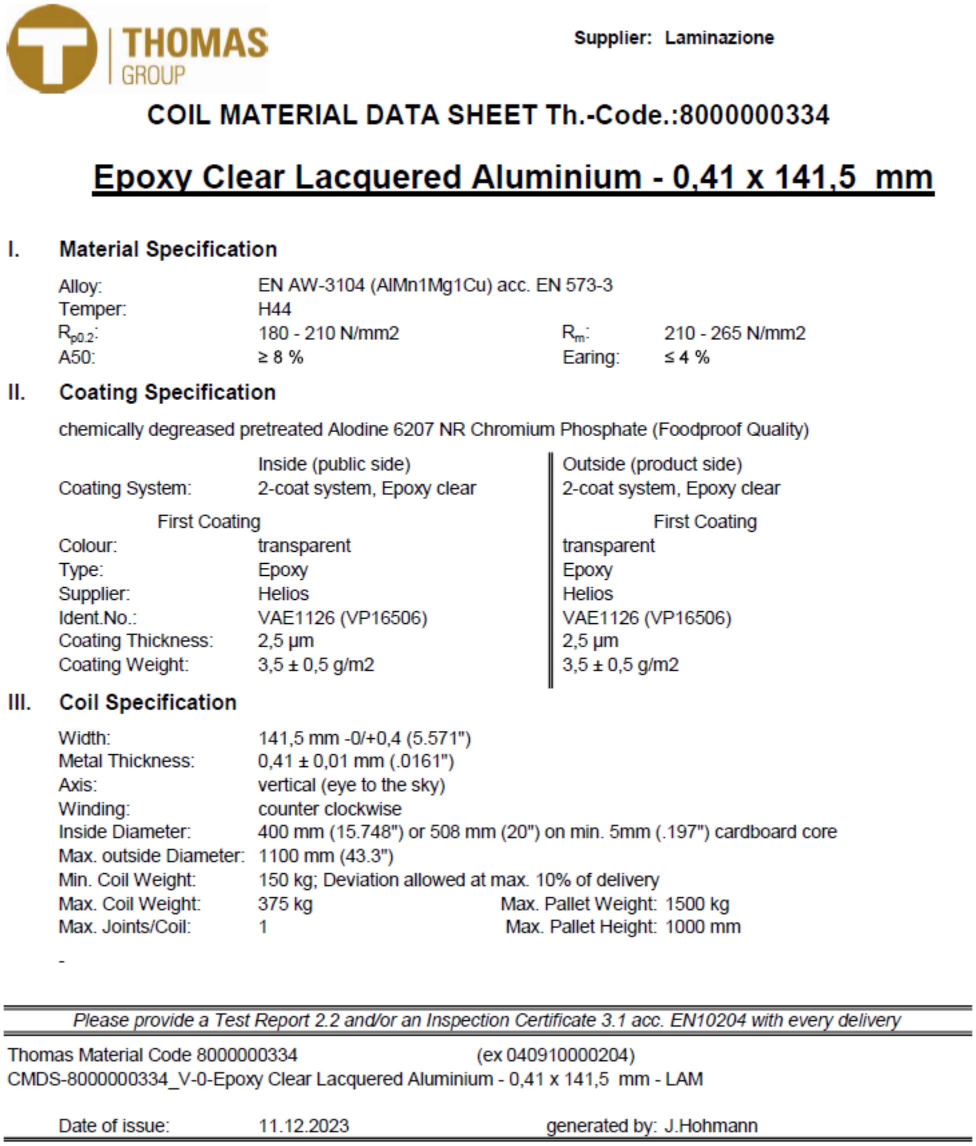
APPENDIX A

MATERIAL DATA SHEET THOMAS – ALUMINIUM 3104



THOMAS GROUP

Supplier: Laminazione

COIL MATERIAL DATA SHEET Th.-Code.:8000000334

<u>Epoxy Clear Lacquered Aluminium - 0,41 x 141,5 mm</u>

I. Material Specification

Alloy:	EN AW-3104 (AlMn1Mg1Cu) acc. EN 573-3		
Temper:	H44		
$R_{p0.2}$:	180 - 210 N/mm2	R_m:	210 - 265 N/mm2
A50:	≥ 8 %	Earing:	≤ 4 %

II. Coating Specification

chemically degreased pretreated Alodine 6207 NR Chromium Phosphate (Foodproof Quality)

	Inside (public side)	Outside (product side)
Coating System:	2-coat system, Epoxy clear	2-coat system, Epoxy clear
	First Coating	First Coating
Colour:	transparent	transparent
Type:	Epoxy	Epoxy
Supplier:	Helios	Helios
Ident.No.:	VAE1126 (VP16506)	VAE1126 (VP16506)
Coating Thickness:	2,5 µm	2,5 µm
Coating Weight:	3,5 ± 0,5 g/m2	3,5 ± 0,5 g/m2

III. Coil Specification

Width:	141,5 mm -0/+0,4 (5.571")		
Metal Thickness:	0,41 ± 0,01 mm (.0161")		
Axis:	vertical (eye to the sky)		
Winding:	counter clockwise		
Inside Diameter:	400 mm (15.748") or 508 mm (20") on min. 5mm (.197") cardboard core		
Max. outside Diameter:	1100 mm (43.3")		
Min. Coil Weight:	150 kg; Deviation allowed at max. 10% of delivery		
Max. Coil Weight:	375 kg	Max. Pallet Weight:	1500 kg
Max. Joints/Coil:	1	Max. Pallet Height:	1000 mm

-

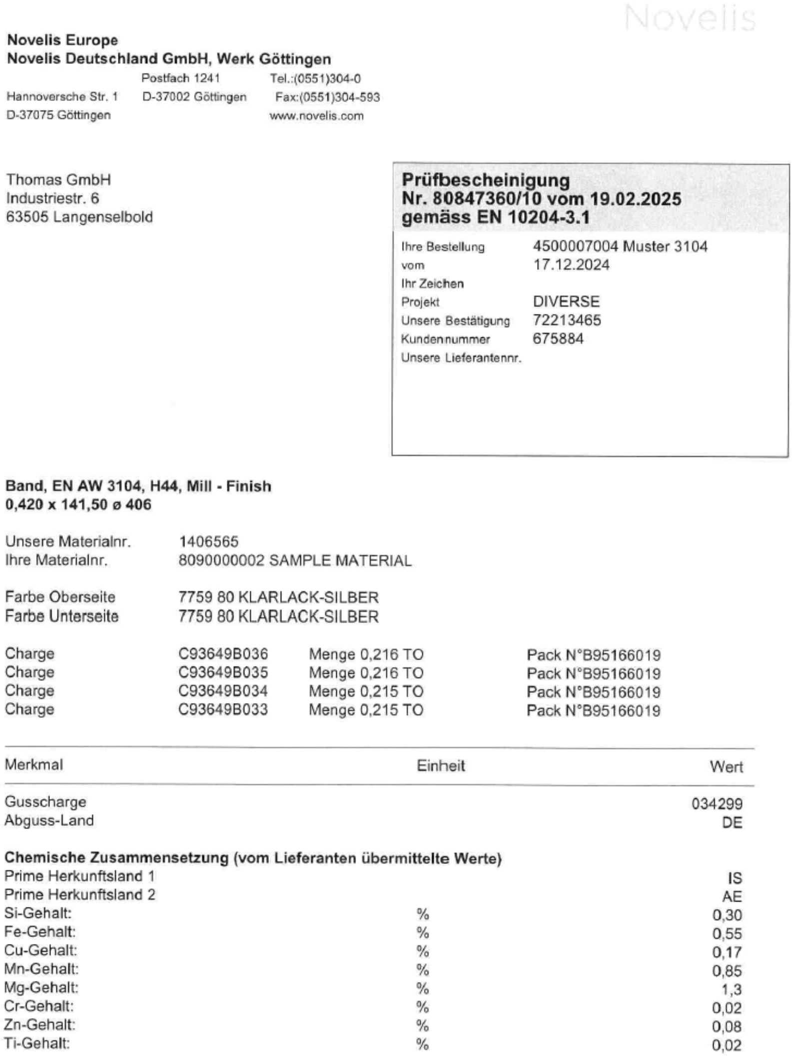
Please provide a Test Report 2.2 and/or an Inspection Certificate 3.1 acc. EN10204 with every delivery

Thomas Material Code 8000000334 (ex 040910000204)
CMDS-8000000334_V-0-Epoxy Clear Lacquered Aluminium - 0,41 x 141,5 mm - LAM

Date of issue: 11.12.2023 generated by: J.Hohmann

APPENDIX B

NOVELIS TEST CERTIFICATE



Novelis

Novelis Europe
Novelis Deutschland GmbH, Werk Göttingen
Postfach 1241 Tel.:(0551)304-0
Hannoversche Str. 1 D-37002 Göttingen Fax:(0551)304-593
D-37075 Göttingen www.novelis.com

Thomas GmbH
Industriestr. 6
63505 Langenselbold

Prüfbescheinigung
Nr. 80847360/10 vom 19.02.2025
gemäss EN 10204-3.1

Ihre Bestellung	4500007004 Muster 3104
vom	17.12.2024
Ihr Zeichen	
Projekt	DIVERSE
Unsere Bestätigung	72213465
Kundennummer	675884
Unsere Lieferantennr.	

Band, EN AW 3104, H44, Mill - Finish
0,420 x 141,50 ø 406

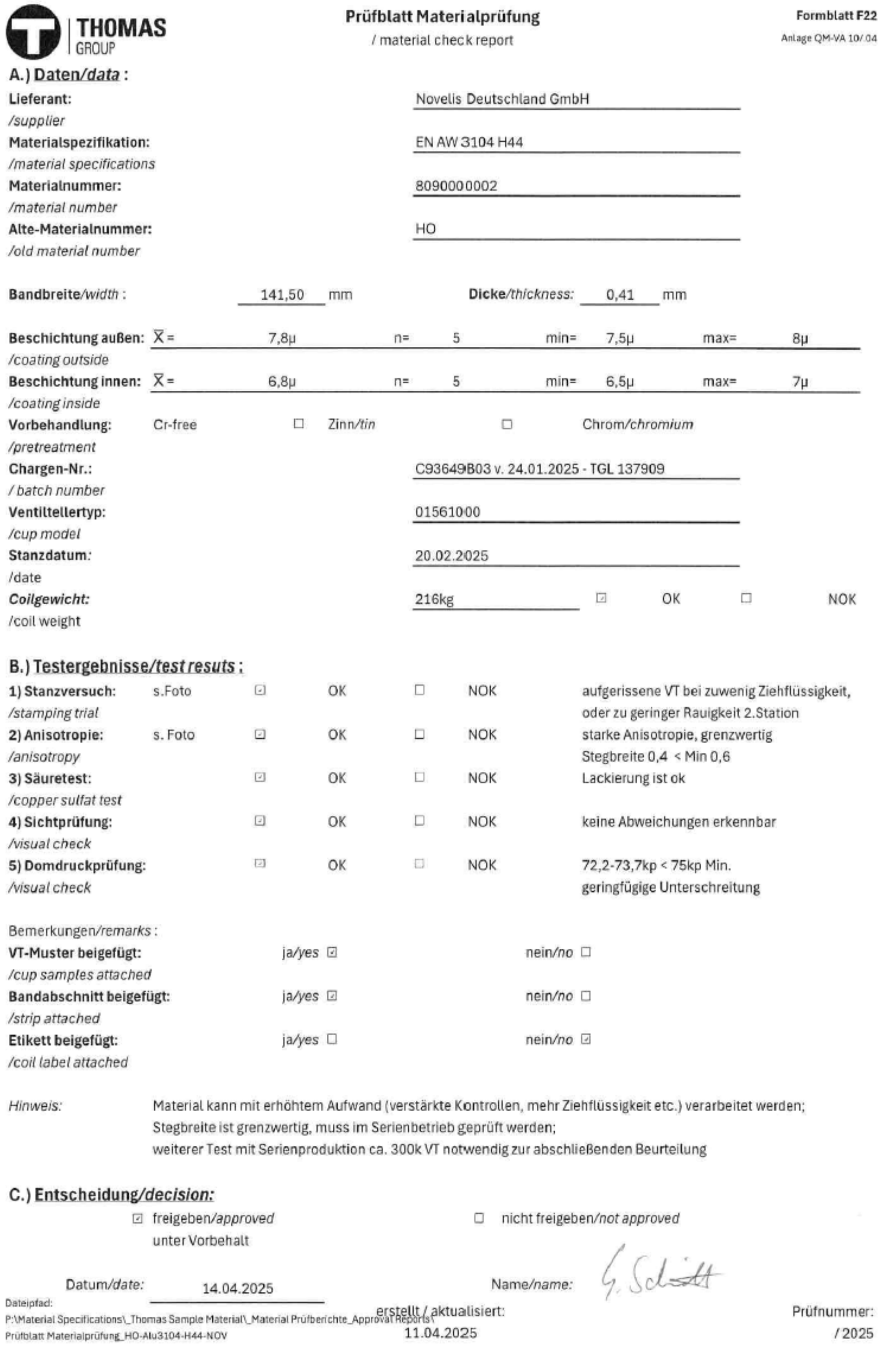
Unsere Materialnr.	1406565
Ihre Materialnr.	8090000002 SAMPLE MATERIAL
Farbe Oberseite	7759 80 KLARLACK-SILBER
Farbe Unterseite	7759 80 KLARLACK-SILBER

Charge	C93649B036	Menge 0,216 TO	Pack N°B95166019
Charge	C93649B035	Menge 0,216 TO	Pack N°B95166019
Charge	C93649B034	Menge 0,215 TO	Pack N°B95166019
Charge	C93649B033	Menge 0,215 TO	Pack N°B95166019

Merkmal	Einheit	Wert
Gusscharge		034299
Abguss-Land		DE
Chemische Zusammensetzung (vom Lieferanten übermittelte Werte)		
Prime Herkunftsland 1		IS
Prime Herkunftsland 2		AE
Si-Gehalt:	%	0,30
Fe-Gehalt:	%	0,55
Cu-Gehalt:	%	0,17
Mn-Gehalt:	%	0,85
Mg-Gehalt:	%	1,3
Cr-Gehalt:	%	0,02
Zn-Gehalt:	%	0,08
Ti-Gehalt:	%	0,02

APPENDIX C

THOMAS TEST REPORT – NOVELIS ALUMINIUM 3104



THOMAS GROUP

Prüfblatt Materialprüfung
/ material check report

Formblatt F22
Anlage QM-VA 10/.04

A.) Daten/*data* :

Lieferant: /*supplier*: Novelis Deutschland GmbH
Materialspezifikation: /*material specifications*: EN AW 3104 H44
Materialnummer: /*material number*: 8090000002
Alte-Materialnummer: /*old material number*: HO

Bandbreite/*width* : 141,50 mm **Dicke**/*thickness:* 0,41 mm

Beschichtung außen: /*coating outside*	$\overline{X}$ =	7,8µ	n=	5	min=	7,5µ	max=	8µ
Beschichtung innen: /*coating inside*	$\overline{X}$ =	6,8µ	n=	5	min=	6,5µ	max=	7µ

Vorbehandlung: /*pretreatment*: Cr-free ☐ Zinn/*tin* ☐ Chrom/*chromium*
Chargen-Nr.: / *batch number*: C93649B03 v. 24.01.2025 - TGL 137909
Ventiltellertyp: /*cup model*: 01561000
Stanzdatum: /date: 20.02.2025
Coilgewicht: /coil weight: 216kg ☑ OK ☐ NOK

B.) Testergebnisse/*test resuts* :

1) Stanzversuch: /*stamping trial*	s.Foto	☑	OK	☐	NOK	aufgerissene VT bei zuwenig Ziehflüssigkeit, oder zu geringer Rauigkeit 2.Station
2) Anisotropie: /*anisotropy*	s. Foto	☑	OK	☐	NOK	starke Anisotropie, grenzwertig Stegbreite 0,4 < Min 0,6
3) Säuretest: /*copper sulfat test*		☑	OK	☐	NOK	Lackierung ist ok
4) Sichtprüfung: /*visual check*		☑	OK	☐	NOK	keine Abweichungen erkennbar
5) Domdruckprüfung: /*visual check*		☑	OK	☐	NOK	72,2-73,7kp < 75kp Min. geringfügige Unterschreitung

Bemerkungen/*remarks* :

VT-Muster beigefügt: /*cup samples attached*	ja/*yes* ☑	nein/*no* ☐
Bandabschnitt beigefügt: /*strip attached*	ja/*yes* ☑	nein/*no* ☐
Etikett beigefügt: /*coil label attached*	ja/*yes* ☐	nein/*no* ☑

Hinweis: Material kann mit erhöhtem Aufwand (verstärkte Kontrollen, mehr Ziehflüssigkeit etc.) verarbeitet werden;
Stegbreite ist grenzwertig, muss im Serienbetrieb geprüft werden;
weiterer Test mit Serienproduktion ca. 300k VT notwendig zur abschließenden Beurteilung

C.) Entscheidung/*decision:*

☑ freigeben/*approved* unter Vorbehalt
☐ nicht freigeben/*not approved*

Datum/*date:* 14.04.2025
Name/*name:*

Dateipfad:
P:\Material Specifications_Thomas Sample Material_Material Prüfberichte_Approval Reports\
Prüfblatt Materialprüfung_HO-Alu3104-H44-NOV

erstellt / aktualisiert: 11.04.2025

Prüfnummer: /2025

APPENDIX D

TEST REPORT - NOVELIS ALUMINIUM 3104 – CUP SAMPLES